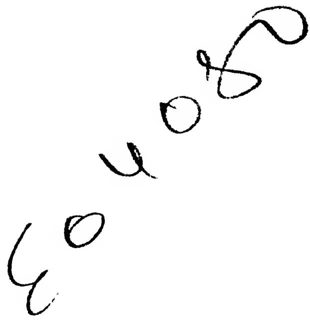


ACOUSTICS, LIGHT, AND HEAT.

ACOUSTICS,

LIGHT, AND HEAT

INTENDED AS AN

Introduction to the Study of Physical Science

ADAPTED TO THE REQUIREMENTS OF THE SCIENCE AND ART DEPARTMENT (ELEMENTARY STAGE) AND VARIOUS OTHER EXAMINING BODIES.

BY

THOMAS W. PIPER,

AUTHOR OF VARIOUS WORKS ON ARITHMETIC;
LATE NORMAL MASTER IN ST. JOHN'S COLLEGE, BATTERSEA.

LONDON:
GEORGE PHILIP & SON, 32 FLEET STREET;
LIVERPOOL: CAXTON BUILDINGS, SOUTH JOHN STREET,
AND 49 & 51 SOUTH CASTLE STREET.
1880.

TO

MR HARRY GRIMSHAW, F.C.S.,

IN KIND REMEMBRANCE OF PAST INTERCOURSE,

This Book

IS DEDICATED

BY

HIS AFFECTIONATE FRIEND,

THE AUTHOR.

PREFACE.

THIS little book covers the ground of the Elementary Examination by the Science and Art Department in Acoustics, Light, and Heat; but the subjects are here treated in such a way as will, it is hoped, render the book a useful introduction to the study of Physics generally.

The plan of the work is different from that of any manual yet issued to meet the requirements of that examination. It is not a dry epitome; it is an attempt to set forth the great principles of this branch of Physical Science in clear and familiar language, and to illustrate and establish these principles by descriptions of the more important and familiar experiments. The phenomena of Sound, of Light, and of Heat in many respects resemble each other; wherever this is the case, they have been placed side by side; wherever such is not the case, the fact has been stated. The whole of these phenomena, consequently, appear here, not as a number of isolated and independent units, but as members of great classes depending upon great principles.

In arranging the work the Author has had the advantage of several years' experience as Normal Master in the Battersea Training-College. He has thus been able to consider the wants of students in Training Colleges; these wants he has endeavoured to meet. As a rule, he found the students fond of scientific subjects for the Criticism Lessons they were required to give before the masters and the inspectors. He hopes they will find here the matter for such lessons presented in a form suitable for teaching purposes, and with strong beams of light shining

upon the "pitfalls" into which students usually tumble in their lessons on such subjects as the book treats of.

As the student makes his way towards the end of the book he will find that the treatment as well as the subjects increases in difficulty. Such is the design. Every educational work should be so written as to develop the mental powers of its readers as they advance through its pages. We shall shortly issue an Advanced Book on the same subjects, and we hope to work it out on the same principles.

It has been suggested that exception might be taken to the familiar, almost playful, language in some places adopted in this book. It is therefore necessary to explain that the Author has striven to reproduce, as nearly as possible, his lessons to his own pupils in a day-school. He there found the beginners seemed to be helped to an understanding of the matter placed before them by reason of the familiar language he was sometimes able to employ; he has therefore judged it not inexpedient to retain here some of the expressions he adopted in teaching.

To this description of the aim and objects of the present book, the Author is anxious to add his sense of the imperfection of his work. To write a model work on Science would be the worthy object of a lifetime; the present can be considered but as an attempt to supply in a convenient form the wants of those who are preparing themselves for various public examinations, and who have not time nor opportunity for studying the larger and more expensive works in which the necessary information is found.

The Author gratefully acknowledges the help he has received from his friend Mr. Mansfield in revising, correcting, and improving the pages as they have gone through the press.

T. W. P.

LONDON, *January* 1880.

CONTENTS.

CHAPTER I.

PRELIMINARY.

CHAPTER II.

VIBRATORY MOTION IN ITS CONNECTION WITH SOUND, LIGHT, AND HEAT.

CHAPTER III.

RECTILINEAR MOTION, AND ITS MODIFICATIONS IN THE PHENOMENA OF SOUND, LIGHT, AND HEAT.

CHAPTER IV.

THE CONSERVATION OF MATTER.

CHAPTER V.

THERMOMETERS.

CHAPTER VI.

ENERGY: ITS CONSERVATION, SOURCES, AND EFFECTS.

CHAPTER VII.

SENSATION, AS ILLUSTRATED BY THE PHENOMENA OF SOUND AND LIGHT.

ACOUSTICS, LIGHT, AND HEAT.

CHAPTER I.

PRELIMINARY.

1. The Atmosphere. Notwithstanding the apparent absurdity of the idea, it has been proved almost beyond a doubt, that this solid earth upon which we tread is round in shape, or, more correctly speaking, its shape is that of an orange. Of what materials the earth is composed is in some degree a matter of speculation, since it has not been found possible to do more than theorise concerning the condition and composition of the central portions of our planet, though chemists and geologists have busily examined the composition and properties of the substances of which its outer crust is made up.

It is not, however, with the earth itself that we have now to deal; we must devote our attention to the study of the invisible cloak or mantle in which it is enveloped, and which rests upon it something as a mist *appears* to rest upon a hill, though there is a great difference between the two phenomena, as we shall hereafter see.

2. Its Association with the Earth. If it were possible to rise up from the earth to such a height as would enable us to view it as a ball, and if the atmosphere instead of being *invisible* were *visible*, we should see the earth surrounded on all sides by an envelope which might perhaps be 100 miles deep, or about $\frac{1}{80}$th of the diameter of the earth, and we might very likely ask ourselves this question: "*Why does the atmosphere cling for ever to the earth? Why doesn't it blow off, or slide off, into the surrounding space?*" We must endeavour to understand why. *Whenever we see a body in motion, we may rest assured that somewhere there is a force causing and supporting that motion;* if a body rests without motion when it appears to be free to move, we conclude either that all the forces tending to produce motion in it counterbalance one another, or that it is not acted upon by a force at all. When we then ask why the air does not slip off the earth, in other words, *move away* from the

earth, we in effect ask why some force does not compel it to put itself in motion in a direction away from the earth; and that brings us to consider where such a force could spring from; whether or no such a force exists anywhere. *As a fact, there are a great many such forces always at work, endeavouring, so to speak, to draw the air away from the earth,* for it must now be understood that *everybody and everything attracts everybody else and everything else;* we as we sit in a room are attracted each towards the other, and all towards the ceiling, the floor, the walls, and the furniture. In the same way the earth attracts the moon, the sun attracts the earth, each star also attracts the others, and they all—sun, moon, earth, and stars—all attract one another; that is, they all try to draw the rest towards themselves. But they do not all attract other bodies with the same amount of force; under certain circumstances *the heavier a body is the greater is its attractive force;* and this explains why we do not see the baby drawn up towards the ceiling, and why the walls of a room do not rush together with a crash; for the earth is by far the heaviest body near us, and consequently we are all attracted to it more than to anything else; and we, and everything in existence, move always towards that body which draws us with the greatest force.

But as the sun and many other of the heavenly bodies are much heavier than the earth, we should expect that the atmosphere would leave the earth and move off towards the heaviest of these bodies, whereas it does nothing of the sort. To understand this we must explain that *the nearer one body is to another the more they attract one another*, or, to put it the other way about, *the farther two bodies are apart the less they attract one another.* As a matter of fact, it has been proved that if two bodies be in certain positions and then be moved to certain other positions *twice* as far apart as the former, then the bodies attract each other with a force (2×2 *i.e.*) *four* times less in the latter case than in the former, or, more correctly speaking, the force in the latter case is only one-fourth of that in the former. Also, that if the two bodies be placed *three* times as far apart, the attractive force becomes but *one-ninth* of what it was before, &c. &c. Thus it happens that the atmosphere, being close to the earth, remains there, because the force with which the earth attracts it far exceeds that exerted upon it by any other of the heavenly bodies.

3. Its Composition, Properties, and Molecular forces. Now the composition of the air has been very carefully examined; it has been found to consist of two gases (called oxygen and nitrogen) mixed together, with very small quantities of several other gases, and it has also been discovered that if you climb up a mountain, or go up in a balloon, there are certain differences to be observed in the air taken from those heights when com-

pared with air taken from the level of the sea. Let us see what these differences are.

Suppose a boy is lying flat upon the ground, and you lay upon him *one* blanket, he will probably not complain, but if you proceed to pile upon him *two, four, eight, twenty* blankets, he will soon cry out to you to stop; and the more blankets you put upon him the more he will cry out; and the reason is, that the greater the weight of the blankets he has to bear, the greater is the pressure to which he is subjected.

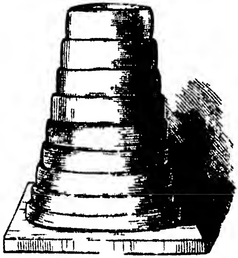


Fig 1

Take another illustration: take a piece of butter rounded like a shallow cheese, and place upon it another piece of the same weight and shape, the under piece will become flattened then add ten or a dozen other similar pieces of butter, placing them one upon the other thus (fig 1), then it will be observed that the farther you go down from the top the more the butter is flattened out, and the reason is that *every piece of butter has to support the weight of all the pieces above it.*

So with the air or atmosphere; we may suppose it to consist of layers

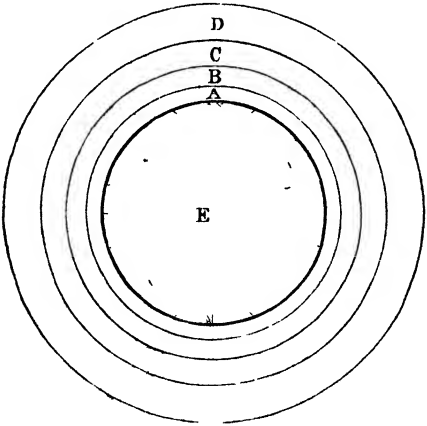


Fig 2

A, B, C, D (fig 2), each and all of which are attracted to the earth, E; it is evident that the layer A has to sustain the pressure caused by the

force with which the other outer layers are attracted to E; also that the layer B is similarly pressed upon by C and D; that C is also pressed upon by D, while D has no such pressure to sustain: in a word, *the farther you rise up from the Earth the less pressure the layer of air in that particular region has to sustain.*

Now if we take a tube, T T (fig. 3), closed at the bottom, place in it some water, W, and then press down upon it with the piston, P, we shall find that it is impossible to squeeze the water, W, into a much smaller space; in fact, that the apparatus would more easily break than the water submit to occupy a much smaller space. If we take out the water, and try wine or beer or any other *liquid*, we shall find that though some of them will allow of more compression than others, there is not one which will submit to occupy a much smaller space. But if we fill the tube with air, or oxygen, or hydrogen, or any other *gas* (or mixture of gases), the case becomes quite a different one; the more heavily we press down the piston, P, the more the gases become compressed, and they will often permit themselves to be forced into a quarter or a tenth of the room they occupied before.

Fig 3.

If, then, the air were *a liquid*, the weight of air sustained by the layer A would not much affect its volume, *i.e.*, its size or bulk; but as the air is a mixture of *gases*, the effect of the pressure of the layers B, C, D upon A is to cause the air in A to become compressed—*i.e.*, to make it occupy a less space; and consequently it is easy to see that the higher we rise up from the surface of E the less compressed the air must be, and this is just what we find in making balloon ascents.

But suppose a certain room will conveniently hold 100 people: it is clear that if the same number of people be forced into a room only half its size the crowding will be dreadful—or, to use a common phrase, the crowd will be very DENSE; and it is also plain that the smaller the room into which these 100 people are pressed the *denser* will the crowd become. So with the atmosphere: the *nearer you are to the earth the denser is the atmosphere*—or, to put it the other way about, the higher you rise from the earth the RARER (*i.e.*, less closely compressed) is the atmosphere.

Again, it is a matter of every-day experience that the more closely a crowd is packed the more desperately each person in it struggles for room: in other words, the more heavy the pressure the more strong is the resistance. And each little particle of which the air is made up has, so to speak, as decided a disinclination to be squeezed up as has any human being; consequently, the more dense the air is the more it struggles for room. Now, when you take a piece of the stuff called ELASTIC and stretch it out, the more you stretch it the more it tries to

return to its former shape. It is because of this power (by which it resists extension and tends to resume its former shape after being extended) that it is so named, for ELASTICITY is the name given to that power by which bodies resist extension, and tend to return to their original shape after having been extended.

We thus learn that air is rendered DENSE by compression (that is, by subjecting it to weights or forces which compel it to occupy less room), and that as its density increases so must its ELASTICITY also increase. It is necessary here to remark that when air or any gas suffers compression, the particles of which it is composed do not each suffer a diminution of volume; the gas *as a whole* does occupy a smaller amount of space, but the room occupied by each individual particle is NOT lessened—the difference is in the amount of space remaining unoccupied between the particles. Just in the same way, when people are crowded together they do not each actually fill less space than when the crowd is less dense, *but there is in the denser crowd less space remaining unoccupied between and among the persons composing the crowd.*

In Fig. 4 let J be a glass jar containing eight quarts of atmospheric air (or any other gaseous body, *i.e.*, any other gas or mixture of gases), and let P be a plate upon which J fits air-tight. By means of an air-pump let us now draw off from J just four quarts of air through the tap, T, which we immediately turn to prevent air from entering J again. We shall find that instead of J being now but *half full*, as we might perhaps have expected, it will be *quite full*, for the four quarts of air we left in J will expand at once and fill J once more.

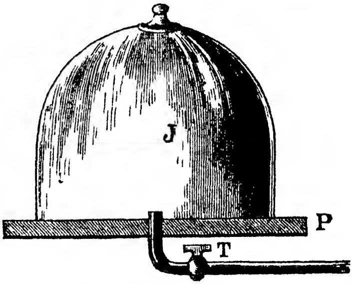


Fig 4.

If we now remove four quarts of this expanded air, we shall find that the remainder will again expand, and once more J will be full of air.

Proceeding in this way, we should find that as often as we removed from J any part of the air, or other *gaseous* body, which it contained, the remaining portion would at once expand to fill the whole of J.

If, however, we suppose Fig. 5 to represent a very strong tube, TT, closed at the bottom, containing the liquid, W, and having a piston, P, working air-tight in it; then if P be raised it is evident that no air can get in between P and the water, consequently there will be a vacuum created between P and the surface of W; for this *liquid*, W, will *not* expand to fill the unoccupied space as the *gas* did in Fig. 4.

Here we see another difference between a liquid and a gas, *viz.*, that at fixed temperatures a certain weight of any *liquid* always occupies a certain fixed amount of space; in other words, has a certain volume, and shows no tendency (exhibits no inclination) to occupy a greater volume; whereas, under the same circumstances, the volume occupied by a given weight of any *gas* is very variable, and depends only upon the amount of vacant space (or, the size of the vacuum) into which it has the opportunity of expanding; in a word, there is practically no limit to the volume of the vacuum which a given weight of air can fill.

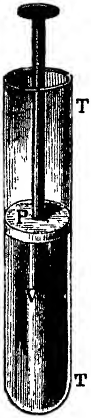


Fig. 5.

Let us now endeavour to understand the reason of this difference between the behaviour of a liquid and that of a gas. Let A, B, C, D, E in Fig. 6 represent five balls connected together by very strong elastic bands, which, as represented in the figure, are stretched to their utmost tension; it is clear that the action of these bands will be to draw all the five balls together, and that it will be a matter of much difficulty to increase the distance between them. These bands represent a force which operates ever between the particles of which every body is composed, an attractive force called the force of *cohesion*, similar in its operation to the force by which the atmosphere is kept in proximity to the earth, which latter force is called the force of *gravitation*.

The action of the force of *cohesion*, if left to operate by itself, would evidently be to draw all the particles of bodies so closely together that they would touch one another, and so touch one another that there would be as little space as possible remaining unoccupied between them; and that being the case, it would be next to impossible to compress any body whatever into a smaller space, or to cause any body whatever to occupy a larger space; whereas, as a matter of fact, it is possible to cause all bodies to expand, and so to occupy more space than they do under any given conditions. The explanation of this fact is not far to seek: it will be shown hereafter that, as a rule, *all bodies expand when heated.* But if any given weight of iron, or water, or gas of any kind, be made to occupy a greater space than it does at present, it is clear that all the individual particles of this body must be pushed farther apart, and to do this *we require the assistance of some force acting in a manner exactly the reverse of that in which cohesion operates: this force is* HEAT.

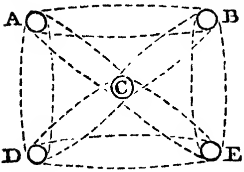


Fig. 6.

In Fig. 7 let F, G, H, J, K represent five balls, between which are placed very powerful springs, all tending to force these five balls asunder. Here we have represented a force acting in a manner the exact reverse of that represented by the elastic bands of Fig. 6. These springs represent a REPULSIVE force—viz., that of HEAT.

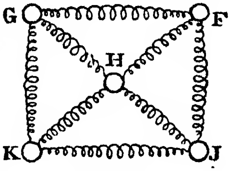


Fig. 7.

The action of the force of HEAT would therefore be to force apart the particles of all bodies containing heat, and it would appear that the more we heated a body the more this repulsive force between its constituent particles ought to increase—*i.e.*, the more the behaviour of that body should resemble that of a *gas*, and the less it should resemble that of a *solid* or a *liquid*. Experiments confirm us in this supposition, for by heating ICE, which is *solid* WATER, we convert it first into a *liquid*—viz., ordinary water—and then into a *gas*—viz., STEAM; and other bodies exhibit the same phenomena. On the other hand, if we make a body *colder* (which is done by subtracting from it some of its heat, as we shall see hereafter), we, in almost every case, cause its volume to diminish; in other words, we cause it to occupy less space—and this is as true of gases as of liquids and solids. This is just what we might have expected, for if *the addition of heat* causes the volume of a body to *increase*, it is only reasonable to expect that *the subtraction of heat* would cause its volume to *decrease*. The same is clear from our illustration by Fig. 7; for while an *increase* of heat in the body increases the strength and tension of the springs, so to speak, a decrease, or *diminution*, of heat will of course diminish the power of the springs.

Now, if a body contained no heat at all—though we have no reason to suppose such a body has ever yet been obtained—there would be, of course, no force of repulsion existing between its particles: the force of *cohesion* would be left to work its own sweet will without let or hindrance, though, under ordinary circumstances, not without help. The help here referred to is *the pressure of the atmosphere*, the action of which we must now make clear.

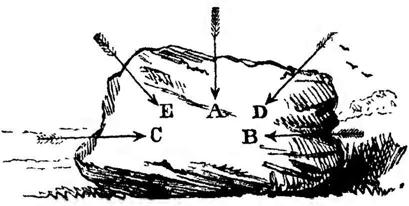


Fig. 8.

Let us suppose that the block of stone represented in Fig. 8 is absolutely cold: then the force of cohesion is unhindered in its action, which action tends to compress together the particles of stone forming the solid block.

But the atmosphere in which this mass of stone stands immersed presses upon it in the directions indicated by the arrows A, B, C, D, E, because the air which surrounds the block on all sides is compressed by the atmosphere above it, and in its struggles for room in resisting this compression it exerts a pressure upon the block on all its sides. The same thing happens when a stone is dropped into the sea. In Fig. 9 the stone A, in making room for itself in the water, has to force away just as much water as occupies the same volume as A, which water, being pressed down from above, resists this displacement by A, and continually occupies its influence in tending to remove A from the position it has by usurpation obtained in the water. The water, in fact, presses upon A on all sides, thus endeavouring, as it were, to force it back to the surface of the water; but, failing that, the influence of the water upon A clearly is to compress all its particles together, as shown by the arrows.

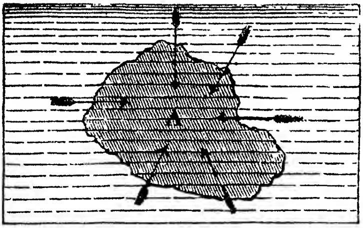


Fig. 9.

Before leaving this part of our subject, it should be remarked that the sum of the forces acting upon A in Fig. 9 is clearly equal to the weight of just as much of the liquid in which A is immersed as occupies the same volume as A; in other words, "*every body immersed in a liquid is subjected to an upward pressure equal to the weight of the liquid displaced.*"

To return to Fig. 8. The block there represented is immersed, not in a liquid, but in a gas, or, rather, a mixture of gases; but this gaseous body affects the block in a manner similar to, though not with a force equal to, that in which the liquid of Fig. 9 acts upon A—*i.e.*, it exerts upon it a pressure equal to that of the pressure of the atmosphere upon as many square inches as are equal to the exposed surface of the block; and the effect of this pressure is clearly to assist the force of cohesion in pressing together the particles of the stone.

If, however, a body *does* contain heat, this heat in almost every instance occupies itself in holding asunder the particles of the body—*i.e.*, *it resists any compression of the body, and tends to produce expansion of the body.* In such cases, then, we have two opposing forces at work between the molecules of the body—viz., the attractive force of COHESION (assisted by the ATMOSPHERIC PRESSURE) and the repulsive force of HEAT; and there are three possible states in which these may be relative to each other, viz.:

1. **That in which the combined forces of Cohesion and Atmospheric Pressure exceed that of Heat**: this is the state in which are all bodies existing as solids or as liquids.

2. **That in which the combined forces of Cohesion and Atmospheric Pressure are just balanced by that of Heat**, or, in other words, that in which the expansive force of heat is of a magnitude exactly equal to the combined attractive forces of cohesion and atmospheric pressure. This is the condition in which a liquid body is when just about to assume the gaseous state, when, in fact, the addition of heat in however small a quantity will convert the liquid into a gas, when, indeed, the addition of this extra heat will so increase the repulsion already existing between the particles of the liquid that the body becomes an example of the next state, *viz.*

3. **That in which the combined forces of Cohesion and Atmospheric Pressure are exceeded by that of Heat**: this is the condition in which are all gases, including steam, which is simply gaseous water, *i.e.* water in the state of gas.

The present is a fitting opportunity for explaining the meaning of the terms "*solid*, *liquid*, and *gas*," as used in works on science. If a block of ice, taken at a temperature below the freezing point of water, be subjected to the action of heat, it gradually rises in temperature (*i.e.* in amount of *sensible heat*, by which we mean heat which can be detected by a thermometer), and soon begins to melt, that is, to change from the *solid* into the *liquid* state. If heat be applied to the ice for a period sufficiently long, it will be found at last that all the *ice* has become changed to *water*; in other words, the whole lump of *solid* water has changed to *liquid* water. But if the application of heat be still continued, the liquid water assumes ultimately a new form, *viz.*, that of *steam* or *gaseous* water. To observe these phenomena, in the flask, F of Fig. 10, place a number of lumps of ice, apply heat by means of the spirit lamp, L, and watch the successive changes take place.

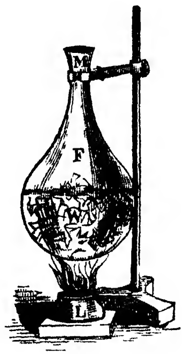


Fig 10.

If the mouth, M, of the flask were closed so that the steam could not escape, then the expansive force generated by the continued action of the heat would be so great that the flask would burst; in other words, the force with which the particles of the water would be driven asunder by the action of the heat would so greatly preponderate over the attractive influences of cohesion and atmospheric pressure, that the water particles (now in the shape of steam), in their extreme anxiety to get as far from one another as possible, would struggle so fiercely for room that it would become impossible for the sides of the flask to resist their outward pressure, and the flask would consequently

burst asunder with a crash; and so it would, were it made of brass. The explosive power of confined steam is something tremendous; to its influence are due many useful as well as many disastrous occurrences: a steam-engine drawing a railway-train is an instance of the former; the same engine, a shapeless wreck with a thousand fragments of its former machinery scattered far around, is a striking instance of the latter, and vividly illustrates the almost irresistible force of confined steam; or, to put it another way, the tremendous power by which the particles of a gaseous body are driven asunder by the action of heat.

With this previous explanation and illustration the reader will now be prepared for the following definitions of the three states or conditions of matter :—

1. **The Solid state** is that condition in which a mass of matter is when its particles are held together by forces which are not only sufficient to counteract the force, or forces, which tend to drive the particles asunder, but are so overwhelmingly greater than they that they maintain these particles in certain fixed positions, from which they cannot be moved without the expenditure of new force.

2. **The Liquid state** is that condition of matter in which its particles are held together in a mass by forces which, though exceeding, or, at least equal to, the forces tending to thrust the particles asunder, yet do not so greatly exceed them as to be capable of preventing the particles from moving freely among one another.

3. **The Gaseous state** is that condition in which is a mass of matter when its particles tend to fly asunder, and so to cause the body composed of those particles to fill all the unoccupied space into which it has the opportunity of expanding.

From these definitions it will be observed that the characteristic mark of a *solid* is the fixed positions of its particles; that of a *liquid* is the mobility of its particles among one another; that of a *gas*, its tendency to occupy increased space.

Returning now to the consideration of Fig. 7, it becomes evident that the more the five balls, F, G, H, J, K, are driven together by any force, the shorter become the springs, and consequently the more great their resistance becomes. When therefore we bring a pressure to bear upon a quantity of air, we, in effect, force together its particles in spite of the resistance of (the springs or) the repulsive forces acting between them. It is clear, however, that just as the elastic force of the springs is increased by their being forced to occupy less space, so the elasticity of the air is also increased by its being rendered more dense. Further, we now understand why the air expands in Fig. 4; *viz.*, that since one-half the air is removed from J, there is nothing to resist the action of the

(springs, that is the) elastic force tending to thrust asunder the particles of air composing the remainder, which consequently take up positions so far apart that they occupy the whole of J.

There is one other point to be noticed. It has been shown above that the tendency of any force operating in such a manner as to compress a body, *i.e.*, to shorten the distance between its component particles, must be to increase the elasticity of that body by, so to speak, compressing the elastic springs acting between those particles. But if the strength and energy of those springs could be increased *without compressing them*, then the elasticity of a body might be increased *without subjecting it to compression.* Now, experiments prove most clearly that the action of heat applied to bodies is almost invariably to increase their length and breadth and depth—in a word, *to increase their volume;* and this increase of volume can only be brought about by increasing the repulsive forces acting between the particles of the body, which, otherwise expressed, is, increasing the elasticity of the body. There are therefore two methods by which the elasticity of a body may be increased; viz., first, by subjecting it to pressure in such a manner as *to diminish its volume;* second, by subjecting it to heat *without diminishing its volume.* Cold, on the other hand, will of course diminish the elasticity of a body.

4. Experimental Proof of the Elasticity of the Air.

(1.) In Fig. 11 let C be a cylinder open at both ends, but having its upper surface covered with a piece of wet bladder in such a manner as to be air-tight. The bladder having dried, the cylinder is placed upon the plate, P, of an air-pump, as shown in the figure. In this position the bladder remains as it was before placing it upon the plate, *i.e.*, it continues to maintain a level surface, the reason being that at present the elasticity of the air confined in C is equal to that of the air pressing downwards upon the bladder; the bladder is therefore forced upwards with a pressure equal to that with which it is forced downwards.

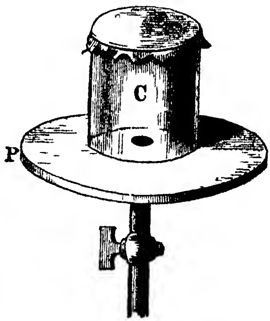


Fig. 11

Now let the air from C be gradually removed by the air-pump, then the force pressing the bladder *upwards* will gradually diminish as successive portions of the air in C are withdrawn, while the pressure *downwards* upon the bladder will remain undiminished. The bladder accordingly assumes a concave shape when viewed from above, and finally bursts inwards with a loud report.

If, instead of exhausting the cylinder, C, we *condense* the air contained in it by forcing in more air, then the bladder will present a *convex* surface when viewed from above, and will at last burst *upwards* and outwards instead of downwards, because in that case the density of the enclosed air being much greater than that of the outside air, the *elasticity* also of the former will greatly exceed that of the latter, and therefore the force tending to press the bladder upwards will greatly exceed that tending to force it downwards, and hence the explosion and the circumstances thereof.

(2.) Let R of Fig. 12 be the receiver of an air-pump, and let B be a small bladder partially filled with a very little air. Let the bladder be now closed by the stop-cock, S, and then let the receiver, R, be exhausted by means of the air-pump. Then it will be seen that the bladder

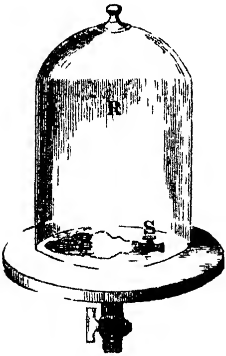


Fig 12.

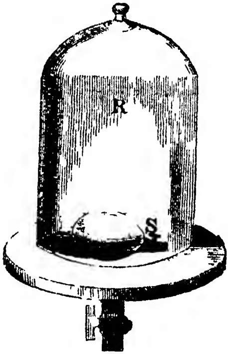


Fig 13.

will swell out gradually as the exhaustion proceeds. (See Fig. 13.) It may perhaps at last crack and burst if it be not a strong one. The reason is that the air enclosed in the bladder has a greater density, and therefore a greater elasticity, than the rarified air of R, and consequently exerts a greater force outwards upon the sides of the bladder than the rarified air does inwards upon them.

(3.) *Torricellian Experiment.* Let us take the tube, A B (Fig. 14), which is about a yard long and not more than one-third of an inch broad, and fill it with mercury and then invert it into a cistern, C, of mercury. (See D E, Fig. 15.) It will then be found that the mercury will sink down to a level, L (Fig. 15), about thirty inches from that of the mercury in C (thus leaving between D and L a vacuum) and will there remain stationary.

It has been already explained that the regions of the atmosphere nearest the earth are in a state of compression, and that they consequently exert

a great pressure upon the surfaces of all things immersed in them, such pressure being said to be caused by *the elasticity of the air.* This pressure exerts itself therefore upon the surfaces of all liquids exposed to the air, and in consequence of the extreme facility with which the particles of liquids move among and about each other, it is easy to see that any liquid struggling to escape this downward force would move in any direction open to it, whether that direction be upwards or downwards, to right or to left. It is also clear that, besides other opposing forces, this compression of the air, or rather the elasticity of the air caused by this compression, would prevent liquids from rising up in the air. When therefore the tube A B is inverted in C (as D E), we find, *first*, that the whole column of the contained mercury tends to sink down towards the earth, or rather the earth's centre, but to do so we see, *secondly*, that it must increase the amount of the mercury in C, and thus force up the level of the fluid in C *in opposition to the opposing compressing force of the atmosphere*, assisted by certain other forces. Supposing, therefore, that the whole force exerted by the liquid in A B, in its attempt to obey the law of gravitation (the effect of which force is called *the weight of the liquid* contained in D E), is greater than the sum of the forces exerted upon the upper surface of the mercury in C, it is easy to see that the mercury in D E will begin to fall in the tube and to rise in C. But the farther the mercury falls in D E the less becomes the weight of that remaining therein, so that the less the force by which the level of the liquid is depressed in D E the less becomes its tendency so to fall, till at last the weight of the mercury in D E exactly equals that which the elasticity of the air over C can successfully resist; this state of matters being attained, the mercury sinks no more in D E, but remains stationary, as at the point L. Again, if we suppose the liquid to have settled at L, we see clearly that if the pressure of the atmosphere be in any way increased, the result must be an increase of the force which the surface of the mercury in C has to sustain, and consequently the greater is the anxiety it manifests to be out of the way of this superincumbent pressure; the result is a rise in the level of the liquid above the point L at which it formerly stood stationary, for in its efforts to escape the increased atmospheric pressure the liquid in C forces a portion of itself into D E sufficient to render the

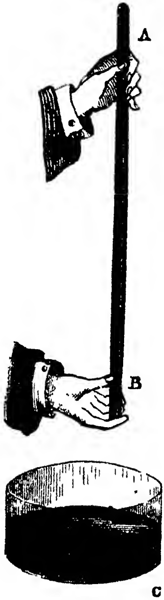


Fig 11.

weight of the contents of D E equal to the utmost the present atmospheric pressure can sustain. The greatest height of mercury thus maintained in position by the atmospheric pressure is never much above thirty inches.

Now, mercury is about 13½ times as heavy as water, consequently it is clear that 30 inches of mercury are as heavy as (30 inches × 13½, *i.e.*, about) 34 feet of water; we should therefore expect that if the atmospheric pressure can support the weight of 30 inches of mercury it could similarly sustain 34 feet of water, and in making pumps it is found that such is the case.

This experiment has been utilised in making instruments called *barometers.* It has been explained above that an increase of atmospheric pressure forces up the mercury in D E higher than it was at first, while a diminution of atmospheric pressure causes a depression of the level of the mercury contained in D E. Now the pressure of the atmosphere at any place varies from day to day and from hour to hour, consequently, the rise or fall of the liquid in such a position as D E becomes a faithful index of the increase or diminution of atmospheric pressure, as the case may be.

Fig. 15.

Such an arrangement as that shown in Fig. 15 is called a barometer, in this case very crude in its conception, and requiring many improvements which it is not at present our purpose to explain.

(4.) We measure the elasticity of a body by the force it exerts, *e.g.*, by the weight it can support, as in the following case. If one body can support twice as much pressure as another body, we say that the elastic force of the former is double that of the latter; or if the same body under certain circumstances supports double the pressure that it does under certain other circumstances, we conclude that the elasticity of the body in the first case is double of that it possesses in the second case.

In the accompanying figure (16) let T T^1 represent a long bent tube open at both ends, but having a stop-cock, S, by which the end T may be closed when desired.

The stop-cock being open, pour in a quantity of mercury sufficient to fill the bend of the tube to the level *a*; then close the stop-cock and pour in more mercury at T. It will be observed that when left to itself the mercury does not now stand at the same level in both arms of the tube T, T^1, but that the level in the arm T^1 is much lower than that in T.

If now we continue to pour in mercury till the level in the arm T^1 stands at *b*—that is, *half-way between its last position, a, and the stop-cock, S*—we shall find that the level in the other arm, T, will be just the same number of inches above the level *b*, that a neighbouring barometer stands at. These facts are thus explained: when both ends of T, T^1 are open, the mercury has the same amount of pressure to sustain in both arms of the tube; but when *S* is shut and more mercury poured in at T, the air now enclosed between *a* and *S* becomes compressed more and more as the level of the mercury below it rises towards *S*; but the more this air is compressed the more its elasticity increases, and consequently the greater becomes the pressure which it exerts upon the advancing level of the liquid in T^1. But all this time the pressure of the atmosphere upon the level of the mercury in T remains unchanged, consequently, the more mercury we pour in, the more we increase the difference between the pressures exerted upon the level of the liquid in T^1 and that of the liquid in T. It is therefore easy to see that the mercury, meeting with more resistance towards T^1 than towards T, will by preference rise rather in the latter than the former, so that at first sight it would appear probable that the liquid would not rise at all in T^1. But, if we consider a moment, it becomes evident that supposing the liquid to be at *a a*, and more mercury to be poured down the tube through the funnel at T, the former level of the liquid in T must be pressed downwards not only by the ordinary atmospheric pressure, but also by the weight of the mercury newly poured in; and this additional force, exerted with a downward tendency in T, goes to balance the force exerted (also with a downward tendency) by the increase of elasticity of the air enclosed in the arm T^1; or, more correctly speaking, it so thrusts down the level of the liquid in T that it forces the level of the liquid to rise in T^1, thus compressing the air contained in the arm T^1, and in this way generating an increase of elasticity in this air, which increase of elasticity goes to counteract the influence generating it with a force continually augmenting till it is at last of power sufficient to effectually resist (and thus neutralise) the tendency of the liquid to rise towards S; at this point equilibrium is established once more.

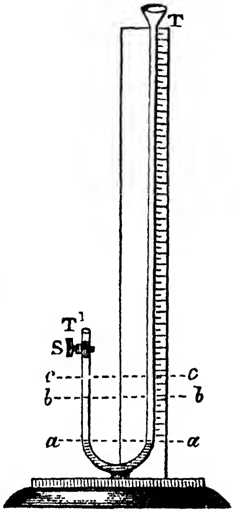


Fig 16.

Now, after the closing of S, and before the addition of the new mercury, the elastic force of the air imprisoned between *a* and *S* was sufficient simply to balance the elasticity of the free atmosphere at that moment, which elasticity is equal to the weight of a column of mercury of the same height as the distance between the second levels of the liquid in T and T^1. But after the level *b* is attained, the elastic force of the air between *b* and *S* is sufficiently great to balance the weight of twice the amount of mercury it did before, for it not only balances the atmospheric pressure upon the level of the liquid in T, but also the same amount of mercury that this atmospheric pressure (upon the liquid in T, that is) is capable of sustaining. Therefore, by diminishing the volume of the air in T^1 to one-half, we have increased its elasticity to double that it was at first.

And if, by the addition of still more mercury to the column in T, we continue to increase the upward pressure upon the level in T^1 till we force it up to C, thus reducing the volume of the air confined in T^1 to *one-fourth* its original volume, we shall find that the elasticity of this confined air has been thereby increased to *four times* its original amount, for it now supports not only the atmospheric pressure, but also three times as many inches of mercury as are read at the moment upon a neighbouring barometer.

By these and similar experiments we are led to observe that the increase of elasticity caused by an increase in the density of a gaseous body is in accordance with the following rule, called

Mariotte's Law—If the Temperature remain constant, the Elastic Force of a given mass of Gas varies inversely as its Volume, and directly as its Density.

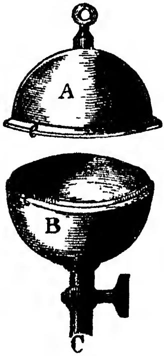


Fig. 17.

(5.) To show now that *the elastic pressure of the atmosphere is exerted in every direction,* we may take the *Magdeburg Hemispheres,* Fig. 17.

A and B are two hollow hemispheres made of brass, and with closely-fitting edges (*e e*). These having been well greased and put together, we experience no difficulty in separating them again so long as they contain air of the same density as that outside them, but as soon as the air has been exhausted from them, through the tube C, we find it necessary to exert great force before they can be separated from each other. The reason is that the elastic force pressing inwards upon them before the air was removed was counterbalanced by that of the air inside them ; but as soon as the inside air was removed there was nothing to counteract the inward pressure of the air outside them, and it became necessary, therefore, to

exert sufficient animal force to overcome the elastic force of the air before we could pull them asunder.

Now, as this experiment is equally effective in whatever position we hold the apparatus, it is clear that the elastic force of the air is equal in all directions.

5. Experimental Proof that the Air has Weight.—Much of what we have said depends upon the fact that *the air has weight,* which amounts to the same thing as saying that the air exerts a steady pressure towards the centre of the earth, which pressure is induced by the action of gravitation.

The following experiments will illustrate this property of the air:—

(1.) Let the globe G be filled with air and weighed. Then let it be exhausted of air by means of an air-pump and the stop-cock C, and then weighed again: it will have lost as much weight as is equal to that of the air withdrawn.

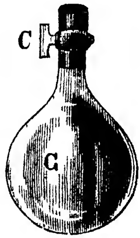


Fig. 18.

N.B.—At the temperature of freezing water, and with the mercurial barometer standing at 760 millimetres (see sec. 4), it is found that *a litre of air* weighs 1·293 grammes; under the same conditions, *a litre of water* weighs 1000 grammes. Hence

$$\frac{\text{The weight of a litre of water}}{\text{The weight of a litre of air}} = \frac{1000}{1\cdot293} = 773$$

So that *water is under these conditions* 773 *times heavier than atmospheric air.*

(2.) The rising of a balloon, and of smoke, in the air may also be taken as indirect proofs that the air has weight. Balloons and smoke each rise through the atmospheric air because they are lighter than the volumes of air which they respectively displace. (Compare Fig. 9.)

A balloon filled with a gas heavier than atmospheric air would not rise, and smoke when it happens to be heavier than the air sinks to the earth.

6. Aqueous Vapour in its Relation to the Atmosphere.—Besides the gases oxygen and nitrogen, of which air is principally composed, there are other gases which, though existing in it in but relatively small quantities, are by no means unimportant as regards the phenomena to which they give rise. Perhaps the most important of these is Aqueous Vapour—that is, water in the gaseous condition.

Pure water, whether it be in the solid condition (as *ice*), or the liquid condition, or the gaseous condition (as "*Aqueous Vapour*" or "*steam*"), is composed of two gases, oxygen and hydrogen; indeed, if the steam generated in the vessel of Fig. 10 be driven through a porcelain tube

heated to intensity, it will be broken up by the heat into its constituent gases, oxygen and hydrogen. The young student will be interested to hear that although water will neither burn nor permit a candle or any such light to burn in it, yet one of its constituent gases—viz., hydrogen—will burn in the air with a blue flame, but a light goes out when plunged into it. On the other hand, although oxygen itself will not burn in the air, a candle or other light when plunged into it burns most brilliantly; so that by decomposing the water we obtain two gases, each possessing properties foreign to the water itself. Substances so combined as are oxygen and hydrogen in this case are said to be *chemically united.*

The oxygen present in atmospheric air is not combined in this way with the nitrogen with which it is mixed. As found together in air, both the oxygen and the nitrogen retain their peculiar properties. Gases existing together in this condition are said to be *mechanically mixed.*

The heat of the sun as it shines upon the earth so acts as to convert the water upon the earth's surface into steam—*i.e.*, invisible watery vapour. The same thing occurs when a kettle boils over the fire: steam leaves the spout of the kettle in an *invisible* condition, but coming then into contact with air much colder than itself, it loses heat and becomes *visible* as a kind of cloud. It is found by experiment that *the hotter a mass of atmospheric air is, the greater is the quantity of water which it can contain in an invisible condition as watery vapour.* When such a mass of air contains as much water in this way as is possible for it to hold in an invisible state, it is said to be *saturated* with vapour.

With this explanation to help us, let us now trace all the changes which a quantity of water undergoes when boiled in a kettle. The first effect produced upon it by the heat is to raise its temperature up to the boiling point. The water then gradually converts to steam, which issues from the mouth of the kettle in an invisible condition, as may be observed by carefully examining the mouth of the kettle. Passing now into the air which surrounds the kettle, and which is cooler than the steam itself, the steam loses some of its heat to the air with which it is in contact, and assumes the visible state, being now, in fact, a multitude of minute drops of water in the liquid form. These drops, being extremely small, float easily in the atmosphere until they either convert again to vapour, in consequence of their mixing with a larger body of air the heat of which is sufficient to maintain them in the gaseous condition, or are further cooled by contact with other cold bodies, in which case they unite with other neighbouring particles of water which are continually forming under the influence of the cold to which the vapour is exposed, and the drops of water thus formed become at last so large and heavy that they no longer float in the air, but descend as drops of rain.

Sometimes this cooling is so large and sudden that the watery vapour converts almost immediately to the solid condition, and then we get a

fall of *snow* instead of a shower of rain; in other words, we experience a fall of water in the solid instead of the liquid condition.

Occasionally it happens that the drops of rain in their downward passage to the earth are frozen in consequence of the loss of heat they undergo in passing through layers of air colder than themselves: we then get a fall of *hail*.

Watery vapour being lighter than atmospheric air, it follows from what we have said above (sec. 5) that it always rises, when free to do so, into the higher regions of the atmosphere; and the lighter this vapour is —that is, the less condensed it is—the higher it will rise above the earth. We thus understand, not only why clouds—which are really watery vapours in the visible condition—rise above the earth, but also why it is that the clouds known as *rain-clouds* always float nearer the earth than the other clouds: for the rain-clouds are composed of the larger drops of water, and are therefore, as it were, the heavier clouds.

Again, since watery vapour is lighter than atmospheric air, it follows that if there be an unusually large quantity of this vapour present in the atmosphere at any place, the pressure on the lower portions of the atmosphere (that is, those portions which are nearest the earth) will be less than would be the case if this vapour were replaced by dry air; from which it follows that an increase in the amount of watery vapour present in the atmosphere will be indicated by a fall in the barometer. But the greater the quantity of vapour present in the atmosphere, the greater is the chance of rain: it is for this reason that a fall of the barometer is usually taken to foretell rain.

We have so far spoken only of one means of cooling air—viz., contact with colder bodies. There is another very important means of chilling air, and that is its own expansion. It has been already observed that air and other gases exhibit a characteristic tendency to expand so as to fill larger volumes: whenever they do spontaneously so expand they always do so at the expense of their *sensible heat*. This leads to an explanation. The total heat in any body may be roughly divided into two parts, one of which is employed as a repulsive energy tending to force the body to expand, while the other part is occupied in giving the body that heat which may be felt by the hand or seen by the eye in its effect on a thermometer (sec. 29), and is hence known as *sensible heat*.

Because the former of these two kinds of heat is not discoverable by a thermometer, it is termed *latent* (*i.e.*, *hidden*) *heat*. If the block of ice in Fig. 10 be taken at a temperature lower than that of freezing water, it will, under the influence of the heat supplied it by the lamp, gradually become warmer and warmer until it reaches the temperature of freezing water. So far all the extra heat it has gained has been indicated by an increase of *sensible heat;* but now a change takes place, for although the lamp still continues to supply heat to the contents of the flask (Fig. 10),

a thermometer placed therein fails to record any increase of heat. The reason is this: the heat which the lamp now supplies is all occupied in converting the ice into liquid water, and is thus becoming *latent*. As soon, however, as this process is complete, and the whole body of ice at the temperature of freezing water has been converted into liquid water at that temperature, the additional heat which the lamp continues to supply shows itself as *sensible heat* by a gradual rise in the temperature of the water, and this continues till the water begins to boil—that is, to convert to steam. At this point there is another temporary stoppage in the rise of the thermometer: the heat is now employed in changing the water to steam, and thus becomes *latent*.

With reference to water, then, we may say that *latent heat is the heat employed in converting ice into water or water into steam;* or, speaking more generally, we may say that *latent heat is the heat employed in effecting a change in the physical state of a body—i.e., either in converting a solid into a liquid or a liquid into a gas.*

When a gas changes into a liquid, or a liquid into a solid, the latent heat in each case is given up by the body which contained it, and it has been found possible to use this heat in such a way as to make it clear that when a body of water converts to ice it parts with as much heat as would raise an equal weight of water through 79·4° C. (or 143° F.) of temperature, and in the same way that when a body of steam changes to water it parts with as much heat as would raise an equal weight of water through 537·2° C. (or 967° F.) of temperature. For this reason it is said that *the latent heat of water* is 79 4° C., and that *the latent heat of steam* is 537·2° C.

To return now to the point at which this explanation became necessary. We have said that whenever air expands spontaneously it undergoes a chilling; in other words, its sensible heat undergoes a diminution, and evidently this is so in consequence of the conversion of a portion of the sensible heat into latent heat, this latent heat being required to enable the air to effect the expansion which takes place in its volume. But we have said also that an increase in the amount of watery vapour in the atmosphere causes a diminution of atmospheric pressure. Suppose, then, a stream of air laden with aqueous vapour beginning to pass through a region of the atmosphere where the air had been much less charged with such vapour: the consequence must be a diminution of the atmospheric pressure, resulting in an expansion of the air in the lower regions of the atmosphere. This expansion will cause a chilling of the expanding air, and this chilling will spread in all directions through the atmosphere, and lead to the condensation of aqueous vapour, the production of a cloud in the sky, and perhaps a fall of rain.

N.B.—The present is a convenient opportunity for adding a few words on what is called the *cold of evaporation*. We may perhaps best explain

what is meant by this if we describe that piece of apparatus which is called the *Cryophorus*, *i.e.*, the "ice-carrier." This consists of a bent tube with a bulb at each end. (See fig. 18a.) In the construction of this apparatus care has been taken to expel the air from it, so that the tube and bulbs contain no gas, except the vapour from the water in the bulb A.

Fig. 18a.

The bulb A is placed in an empty tumbler to keep it from the action of air currents; the bulb B is surrounded with lumps of ice. The consequence of this position of the bulb B is that the vapour in it condenses to water, and to take its place new vapour arises, from the water in A. But to effect this vaporisation heat is required, and this heat is supplied by part of the sensible heat of the water in A, which is thus rendered colder than it was before. But, by the continued action of the ice around the bulb B, this new vapour is in turn condensed to water, and by this means fresh supplies of heat are withdrawn from the water in A till it at last becomes frozen. The heat thus abstracted from the water in A actually goes to melt the ice surrounding B.

7. The Influence of Atmospheric Pressure in connection with the Boiling Point of Liquids.—In connection with Fig. 8 we have endeavoured to show that the pressure of the atmosphere upon bodies immersed in it, is one of the chief agents by which the repulsive action of heat is opposed. To put this once more clearly before the young student, we will remind him that there are two chief forces tending to hold together the particles of bodies, and these two forces are (1.) *the force of cohesion* and (2.) *the pressure of the atmosphere*, and that the chief force by which the action of these two is opposed is *heat*.

Now when a liquid begins to boil, it is in the act of *coming to pieces*, as it were; its particles begin, in fact, to exhibit a strong tendency to separate from each other, and it is clear that the exhibition of this tendency can only be accounted for, on the supposition that the repelling energy of the heat in the liquid is greater than that of the force of cohesion and of the atmospheric pressure combined. From which it clearly follows that if the pressure of the atmosphere be diminished, a less degree of heat will suffice to boil the liquid. It is for this reason that liquids boil at a lower temperature high up on mountain sides than they do at the sea-level. *The lowering of the boiling point is about* 1°C. *for every* 1000 *feet of elevation.*

In consequence of this depression of the boiling point upon mountain

sides, it is found impossible to cook food in open vessels under such circumstances, for the water boils at a temperature which is insufficient for softening the fibres of the vegetables, &c., which it is desired to cook. By using closely fitting covers to the vessels, however, this difficulty can be overcome. In the closed vessel of Fig. 19 the steam, S, in its endeavours to expand presses in all directions, and consequently exerts a downward pressure upon the water, W, the boiling of which is therefore retarded until heat in sufficient quantity to overcome this resistance has been supplied. By this arrangement the pressure due to the presence of steam above the water is made to supplement the pressure of the atmosphere in preventing the water from boiling.

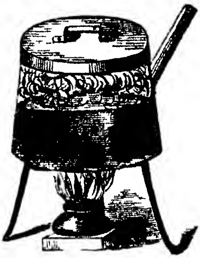


Fig. 19.

An amusing and instructive illustration of the dependence of the boiling point upon atmospheric pressure is the following. In the open flask, F, place a quantity of water and boil it by means of a lamp or Bunsen's burner, L. When the water has boiled briskly for some minutes, take away the lamp, allow the bubbling to cease, and quickly place a tightly-fitting cork in the mouth, M, of the flask.

At the moment of placing this cork in its position all the upper part of the flask is filled with steam, for all the air will have been driven out. Take now a sponge full of cold water and squeeze its contents out upon this upper part of the flask. By so doing a condensation of the steam in F is effected, and the water-drops due to this condensation collect on the cold sides of the flask. But by condensing the steam in this way we reduce the pressure in F upon the water, W, and we thus create conditions under which water requires less heat than usual for its boiling; the consequence is, that the water although decidedly cooler than when it ceased to effervesce, is yet warm enough to boil under its new circumstances, it consequently begins to bubble and boil again, thus presenting the singular spectacle of water boiling in consequence of an application of cold water.

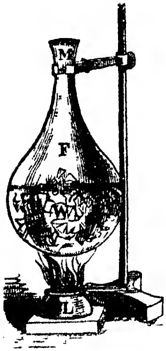


Fig. 20.

8. Atmospheric Currents (involving an explanation of **the Expansion of Gases, the principle of the Fire-Balloon, the causes of the Trade-Winds**), **and the principles of Ventilation.**

(1.) *The Expansion of Gases by Heat.*—In the accompanying figure let F be a flask containing air at the ordinary temperature; and through the cork, C, which must fit air-tight, pass the tube T, T containing a quantity of liquid, L.

Now if the flask, F, be heated by holding it between the hands, or by any other method, the level of the liquid, L, will descend in that branch of the tube which is nearest the flask, and rise up in the other branch. The reason is that the air confined in F expands under the influence of the extra heat supplied to it, and it effects this expansion by forcing the liquid, L, before it.

We have here an example of the expansion which gases undergo under the action of heat: other gases undergo similar expansions under similar circumstances.

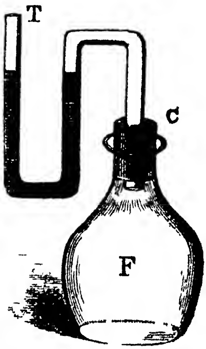


Fig. 21.

In the accompanying figure (Fig. 21) it is evident that the air in F is able to drive the liquid before it, because its elasticity exceeds that of the air outside the flask. If, however, the apparatus be allowed to cool again, the liquid will presently resume its former position, and if the flask, F, be now placed in a vessel of ice it is clear that the elasticity of the air in F will become less, because of the cooling it will undergo; the consequence will be that the level of the liquid will rise in that arm of the tube nearest F, and fall in the other arm. The liquid in each case moves *towards* that quarter in which the pressure (arising from the elasticity) is the least, which, in this case, is the same as saying that it moves from the warmer towards the colder quarter. Advantage has been taken of this fact to construct what is called

The Differential Thermometer. This is an instrument for determining by how many degrees one of two liquids is hotter than the other. The apparatus consists of two flasks, F, F^1, joined by a tube, TT.

When both the flasks (which should be of equal capacities) are at the same temperature the elasticity of the gas (usually air) in the one is equal to that in the other; consequently the levels of the liquid in TT coincide at the points marked O°.

But if the flask, F, be immersed in a liquid of a certain temperature, while F^1 is immersed in another liquid which is 5° warmer, the level of the liquid in TT will rise in the arm of the tube nearest F to the point marked 5°, and will of course descend an equal distance on the side nearest F^1. It is thus possible by this instrument to determine by how many degrees one liquid is hotter than another, without knowing the actual temperature of either of them.

Let us now in imagination take any given bulk of air, and fancy it enclosed in an imponderable globe and suspended in the air; it will neither rise nor fall; but if we now imagine it made hotter while the surrounding air remains at the same temperature, it will follow that, if the globe which encases it offer no resistance, the globe of air will gain in bulk but not in weight; in other words, the heated air will become volume for volume lighter than the air which surrounds it. Now this expansion of the given volume of air is effected by means of heat, and the particular quantity of heat occupied in effecting this expansion is exactly equal to that by which the increase of temperature was, in the first place, supposed to be effected in our imaginary globe of air. When, therefore, the expansion is completed, the air within the globe is left of an equal temperature with that outside it.

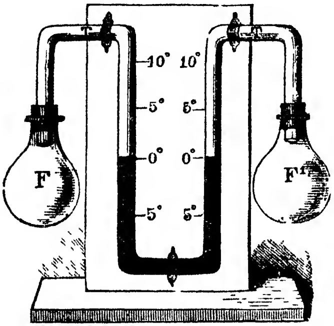


Fig. 22.

But of two given bodies of air (or other gas) at the same temperature, that one will have the greatest elasticity whose density is the greatest; consequently the elasticity of the air in our imaginary globe will be less than that of the air surrounding it; it will consequently not be able to maintain its position, and will be forced to ascend till it reaches a region where the density, and therefore the elasticity, of the air surrounding it is equal to its own, and there it will rest. From all which it is clear that *heated air has a tendency to rise towards the higher regions of the atmosphere, and, as a matter of fact, does so rise when free to do so,* and further, that *this upward motion ceases so soon as the ascending air reaches a point at which the elasticity of the surrounding air is equal to its own.*

We are now ready to understand

(2.) *The Principle of the Fire Balloon.*—A fire balloon is a hollow sphere containing atmospheric air. At the lower part of it there is an opening, and below this opening is a vessel for containing fire. This fire causes a current of heated air to rise through the opening in the balloon, and as this hot air is lighter than the colder air which surrounds it, the balloon rises for reasons similar to those set forth in section 5.

(3.) *Trade Winds.*—It has now been made sufficiently clear that air, sur-

rounded by other air less heated than itself, will rise up from the earth. Now the sun as it shines upon the earth does not heat all parts of it to an equal degree; it is well known that the air *within* the tropics is rendered much hotter in consequence of the sun's action than that in latitudes north and south of the tropics. Consequently, there is a continual upward stream of heated air from this hotter region, and the place of this air is taken by the colder air which rushes from the colder regions north and south of the tropics.

Now, if the earth were a body without motion, the consequence of this continual displacement of air would be a regular north wind in the northern hemisphere of the earth, and a south wind in the southern hemisphere. But, as the earth is in a state of constant revolution from west to east, it follows—from the state of association which obtains between the earth and the atmosphere (see § 2)—that the atmosphere itself is also in a similar state of revolution.

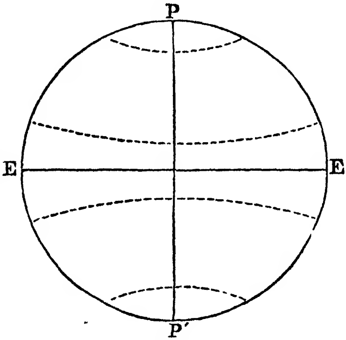


Fig. 23.

In Fig. 23 let the line PP^1 represent the axis of the earth, and EE the equator. It is evident that while the earth revolves about its axis, $P\,P^1$, any point on the equator must perform a greater journey in a given time than any other point north or south of the equator; from which it follows that the velocity of a point situated on the earth's equator is greater than that of a point situated north or south of the equator; from which it again follows that those parts of the atmosphere, which are situated north or south of the earth's equator, move with less velocity than those immediately over the equator.

When, therefore, a current of air sets towards the equator from the northern hemisphere, it approaches a region where the velocity of the earth and the air in moving eastwards is greater than its own: to a person situated, therefore, at the equator such a current *appears* to have somewhat of a westerly direction, because if he stands with his face towards the east he strikes the air with his face, but *being unconscious of his own motion*, he judges that the air must be in motion, and that in a direction contrary to that in which he himself is moving. Let us suppose two trains moving *eastwards* with different rapidities on the same line of rails, and let us suppose that the quicker of the two is some distance behind the other. Suppose now a passenger in the quicker train, uncon-

scious that his train is in motion; as soon as the collision occurs he will confidently affirm that the train with which his train has come in contact was moving westwards when the disaster occurred, whereas it was actually moving in the opposite direction. In the same way, therefore, does a person at the equator judge of the wind which blows from the north: to him it seems to come from the north-east, because it appears to proceed towards the south-west. The wind coming from the regions south of the equator is known as a south-east wind because it appears to proceed towards the north-west.

Because these winds blow regularly and almost uninterruptedly during certain seasons of the year they have been found of much service to mariners, and are of great importance therefore in commerce; hence they have been called *Trade Winds.*

(4.) *The Principles of Ventilation.*—Into a shallow vessel of water stand the glass chimney of an ordinary paraffin lamp, and let a lighted taper float upon the water in the chimney, as shown in the figure. It is found that the taper soon goes out. The reason is that the candle when burning creates a gas called *carbonic acid gas;* in this gas no lighted candle can live. Still this gas, and the air remaining in the chimney, being hot, would rise up and make room for new supplies of air if it were free to do so, but the fact is that a kind of fight takes place at the top, T, of the chimney; the hot air struggles to rush upwards, and the cold air struggles to rush downwards through T, and the consequence is, that while this struggle is proceeding the taper below dies from starvation (*i.e.*, from want of a proper supply of fresh air) and from poison (*i.e.*, from the mischievous effects of the gas it has itself produced). Now, in order to enable the taper to burn in this apparatus all we need do is to place a kind of thin partition in the chimney at T; a bit of tin will do. (See Fig. 25.) As soon as this is put into the chimney at T the hot air rises on one side of the tin, and the cold air descends on the other side. This is an instance of ventilation.

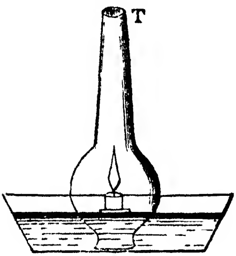


Fig. 24.

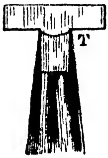


Fig. 25.

Now, it is well known that man, and, in fact, every animal, when breathing gives out the same gases from his body that a candle produces when it is burning in the air. Of these gases there are two, viz., watery vapour and carbonic acid gas. Heat also is produced in both cases. And

further, the effect of carbonic acid gas is the same upon animal life as upon a lighted candle; it is a poison to both of them.

It thus becomes necessary to provide our rooms with means for removing the air rendered impure by being breathed, and for bringing in fresh supplies of purer air. The most ready means for effecting this is the fire, from which a current of air continually ascends up the chimney, and towards which there is therefore a constant current of air from other parts of the room.

Again, another method is to place revolving or other ventilators in the ceiling of the room to be ventilated; the air as it leaves our bodies is always hot, it consequently rises and so escapes through the ventilators placed conveniently for that purpose.

All plans for ventilating our dwelling-rooms must evidently depend upon the circulation of the air in them. The general course of this circulation may be thus described. There is an indraught of air beneath the bottom of the door and through other apertures towards the floor of a room; the greater part of this air proceeds straight to the fire-place where a portion of it is drawn into the chimney current, and so regains the outside of the house, while the remaining portion, having been heated in consequence of its proximity to the fire, rises up before the fire and thus reaches the ceiling; here it spreads out, and after a while becoming cooler than it was on rising, it begins to descend again, and once more crossing the floor of the room is again drawn into the current which is setting towards the fire-place. From this explanation it is evident that

1st. If we wish to get rid of the hot air from a room we must provide it a means of egress from the upper part of the room.

2d. If we place a bit of musk on the mantel-piece in a room in which a fire is burning, the persons near the walls and the door will smell it sooner than one who sits before the fire.

3d. That a lighted candle placed at the *bottom* of the door in the inside of a warm room will have its flame blown *inwards*, but placed at the *top* of the door will have its flame blown *outwards*.

9. **The Air-Pump.**—It now becomes necessary to explain the construction and uses of the air-pump. In the accompanying figure (26) the piston, P, works up and down in the barrel, BB. In this piston is a valve, V, the action of which is assisted by the spring represented in the figure. E is a conical stopper constructed to exactly fit the entrance to the passage, AA. This stopper is attached to a rod which passes up through the piston, and carries a button by which the extent of its upward progress is limited. R is the receiver of the air-pump; it is generally of glass, and is the vessel into which objects are placed when it is desired to observe the effects produced upon them by depriving them of air. It rests upon the highly polished plate of glass or brass, GG. The stopcock,

S, is used to cut off communication between R and the other parts of the apparatus, and thus diminish the chances of air re-entering the receiver.

Suppose the piston, P, to begin to descend; as it does so it carries down with it the rod, CE, and the stopper, E, thus closing the entrance to the tube, AA. The piston now slides down the rod, CE, and therefore the air below the piston becomes compressed, and consequently forces its way out through V. The piston having reached the bottom of the barrel may now be supposed to ascend; in so doing it at first carries up the rod, CE, with it, thus re-establishing the connection between the barrel, BB, and the tube, AA. The upward progress of CE is soon, however, arrested by the button, C; the piston therefore slides up the rod,

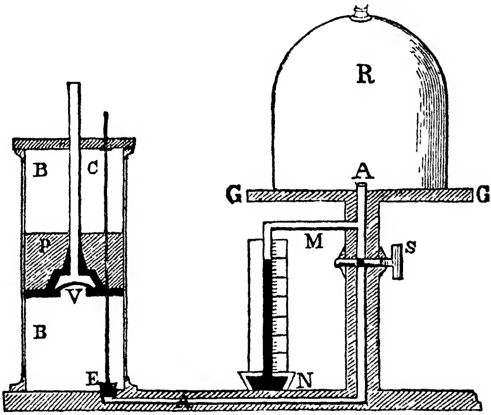


Fig. 26.

CE. As soon as the upward motion of the piston commences, there is a tendency of the outer air to enter the barrel through the valve, V. This tendency, assisted by the action of the spring above the valve, immediately closes it; therefore, in the act of ascending, the piston will remove from the apparatus as much of its contents as is equal to the cubical space described by the piston in passing from its lowest to its highest positions in the barrel.

It will be evident, however, from what we have said on gases (see § 3), that as soon as a certain quantity of air has been thus removed the remainder will immediately expand to occupy the space originally filled by the whole of the air; in other words, each stroke of the air-pump will leave the quantity of air in the apparatus less in weight, but not less in volume. Let it be supposed that each stroke removes one-tenth of the

contents of the receiver; then it is clear that the weight of air remaining in R *after* each stroke is nine-tenths of that in R *before* that stroke, from which it is easy to see that *although we can reduce the air in R to a very fine degree of rarity, we can never produce in it a perfect vacuum*, because, after the last stroke made there will be, say, nine-tenths of the air remaining in it that was there after the stroke before it.

Another cause preventing the obtaining a perfect vacuum by means of an air-pump, is the unavoidable imperfections of the apparatus.

In order to have some indication of the state of exhaustion of the air in R at any particular point of our experimenting with it, a *mercurial gauge* represented by the bent tube, M, in Fig. 26, is employed. The mercury in the cistern, N, is open to the atmospheric pressure of the air *outside* the apparatus, and that in the tube, M, is similarly subject to the pressure of the air *inside* the receiver, R. When therefore the air *within*, and the air *without* R, are of the same elasticity, the mercury in M is of the same height as that in N. But when, by the action of the pump, the density of the air in R is less than that outside it, the mercury begins to rise in M, and it is evident that if a perfect vacuum could be produced in R, the height of the mercury in M would correspond to the reading on a neighbouring barometer. (See § 4, Fig. 14.)

There are many forms of the air-pump; into a description of these it is not our present purpose, however, to enter.

CHAPTER II.

VIBRATORY MOTION IN ITS CONNECTION WITH THE PHENOMENA OF SOUND, LIGHT, AND HEAT.

10. Matter and Motion.—The word *matter* is commonly used to signify *anything which has weight*, whether it be a solid, a liquid, or a gas; in fact, it is usual to speak of matter as existing in the three different forms of solid, liquid, and gaseous. (§ 3).

We wish to speak first of the *translation* of matter, *i.e.*, of its being removed from one place to another.

If the man A (Fig. 27), wishes to give sixpence to B, he wishes to effect a translation of matter from A to B; now he may do this in

Fig. 27

several ways; for example, he may throw it to B, or he may give it to the boy C who will pass it to D, and so on to B; in this latter case the matter (the sixpence) passes from A to B by stages.

Now let us suppose that instead of wishing to give B a sixpence, A wishes to give him a blow in the chest without either of them shifting their positions; he may take a long pole of wood and strike B with the end of that, or, he may strike C and C may strike D and so on; and in this way a *motion* starting from A may be propagated from A to B, and if each of the persons, C, D, E, F, G, H, gives up the blow exactly as forcibly as he receives it, we may then say that *the motion is translated* unimpaired from A to B.

Here we have obtained some idea of a proposition we wish to establish, viz., *that motion, like matter, can be translated from one place to another*, and that, either directly, by means of a rigid body (*e.g.*, a pole of wood)

or, by stages, by means of a number of intervening agents (*e.g.*, a number of boys standing in a line).

In Fig. 28 the man at B is supposed anxious to cause the end of the rope, BA, to vibrate at A, *i.e.*, to move upwards and downwards; he can do this by simply lifting the end, B, up and down several times, whereupon a kind of hump will run along the rope from B to A, as represented by the dotted line in the figure. Here then we see another and more satisfactory instance of the translation of motion from one place to

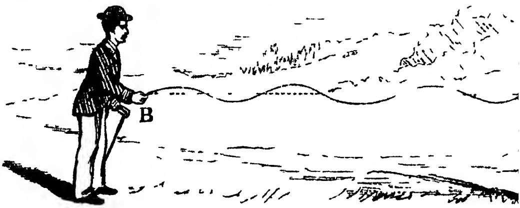


Fig. 28.

another, the motion in this case being propagated through *a solid*, viz., the rope AB.

Again, when we drop a pebble into still water, we notice that a series of waves starts from the point where the pebble struck the water, and travels outwards from that point in concentric circles. In this case we have a translation of motion through *a liquid*, for the agitation of the water at the point where the pebble struck it is communicated to the water surrounding that point, and is by it again transmitted to the water still further from the point of agitation, the motion being in this manner propagated from point to point, till it at last reaches that portion of the water furthest from the centre of disturbance.

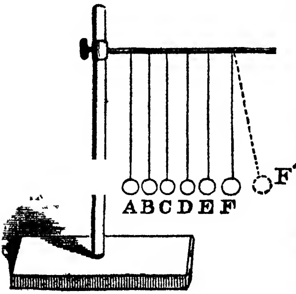


Fig. 29.

Fig. 29 represents a number of ivory balls suspended by light threads; if the ball A be pulled a small distance to the left and then let go it will return with sufficient force to carry it so far beyond its first position that it wi l strike B, which will thus be driven forwards to strike C, and C will then strike D, D will then strike E, and E will strike F, driving it forward to F[1]. Here we see motion transmitted through a system of *disconnected solid bodies.*

Take, now, a tuning-fork, and cause it to vibrate in the position A, thus producing a certain musical note. This note is clearly heard by the

man at B, so that here we see that *a something* passes through the air from A to B; what is that something which so passes, and which, striking upon our ears, causes the sensation of "*Sound.*" It is supposed to be *motion* and to act thus:—The tuning-fork when sounding is undoubtedly in a state of very rapid motion, as we shall show below; this motion it communicates to those particles of the atmosphere which are in close proximity to it, and these again communicate the motion to the parts of

Fig 30

the atmosphere more distant than themselves from A, and the motion thus propagated from point to point of the atmosphere is at last communicated to the air in the ear of the man B, and there causes the sensation of sound.

If the propagation of sound then be, as is believed, a propagation of motion from particle to particle of the atmosphere, we have in sound an instance of *the translation of motion through a gaseous body.*

Fig 31.

Again, a man, M, floating upon the surface of the sea, hears *two* reports of a gun fired *once* at S: the first report reaches him through the water, the second comes to him through the air, thus illustrating the fact that liquids convey sounds with greater rapidity than gases, because of the greater elasticity of the former as compared with its density.

Once more, it is to be remarked that fishes are supplied with auditory apparatus (*i.e.*, apparatus for distinguishing sounds), which gives us

reason to suppose that they can hear, and therefore that sound is transmitted by water. If, then, sound be produced by motion, these two experiments show us that *motion can be translated through a liquid by its own particles.*

And yet again, let the man A slightly scratch his end of the rod; then the noise made by this scratching may be quite inaudible to the man C, standing away from the rod, and yet be distinctly heard by the more

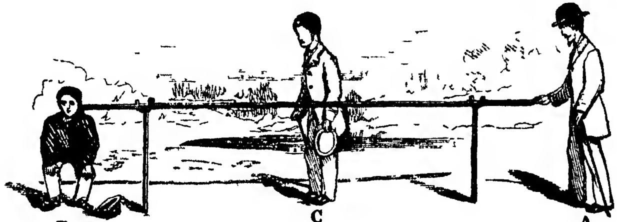


Fig. 32.

distant boy B, who has his ear placed close to the end of the rod, thus proving that *a beam or rod of wood may convey* (*sound, i.e.*) *motion more perfectly than the air.*

Another experiment of the same kind is the following:—A person standing at one end of a long iron railing gets his friend to strike *once* the long iron rod at the top of the railing. The man who is listening hears two reports of the blow, the first reaches him through the iron (which conducts sound fifteen times as fast as the air), the second through the air. This experiment furnishes us with another illustration of *the translation of motion through a solid.*

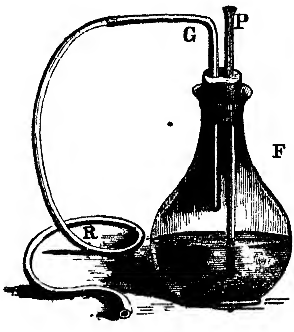


Fig. 33.

We have now shown that motion is propagated by solids, by liquids, and by the air, which is a mixture of certain gases. Take, now, a glass vessel, F, and place in it some pieces of zinc, then pour water down the funnel, P, to cover the zinc, then add a small quantity of sulphuric acid by pouring it also through P. A gas called *hydrogen* will then be evolved from the contents of the vessel, F, and rising up through the glass tubing, G, will pass away by the indiarubber tubing, R, into a suitable reservoir, where it may be

reserved till wanted. This hydrogen is the lightest of all gases, and as we shall hereafter show, although a sound produced in hydrogen is much feebler than one produced, under otherwise similar circumstances, in air, it is yet possible to distinguish a sound produced in hydrogen. It is thus shown that, since sound is produced by motion, *motion can be translated from place to place by the lightest of all gases.*

Now comes the question, "Is there anything lighter than the lightest gas?" The existence of such a substance has not been proved by an experiment, but it is on very good grounds suspected, or rather, *assumed*, that pervading all space not actually occupied by heavy material particles (*i.e.*, particles of matter), there is a certain fluid called *ether*, so extremely light as to be practically, though not actually, imponderable. It is supposed that this ether not only stretches far away beyond our atmosphere, filling up the vast spaces between the heavenly bodies, but that it also occupies all the otherwise vacant space between the particles composing the atmosphere, those composing the waters of the ocean, and those composing all other bodies, solid, liquid, and gaseous. It is also supposed that the sensations of light and heat are produced in us by vibratory motions imparted to this ether by the sun and other bodies giving out light and heat, and conveyed by it to our nerves; if this be so, then are we justified in saying that motion can be transmitted by the extremely (thin, or) rare ether, and also in remarking that motion can be, and ever is, translated from place to place not only by every form of matter, *i.e.*, by everything possessing weight, but also by the ether, which may almost be regarded as an imponderable substance; in a word, there is nothing so light as to be incapable of transmitting some kind of motion.

11. Waves. A consideration of several of the examples we have already given of the translation of motion from place to place would lead us to suspect that most of, if not all, such translations are effected by *to and fro*, or *up and down* movements of the particles through which such motion is propagated. It is supposed that sound, light, and heat are all propagated by such movements, to which the term *vibrations* has been applied. This term requires a little explanation:

(1.) *A pendulum*, as it oscillates backwards and forwards, is said *to vibrate*, and the movement of the pendulum in one direction is called in France an *oscillation* or *vibration*, while its motion both backwards and forwards constitutes a *complete* or *double vibration*, but in England and in Germany this *double or complete vibration* is called *a vibration*, the motion of the vibrating body in one direction only being termed a *semi-vibration*. The time occupied by a pendulum in making a vibration is called *the period of the vibration*, and the distance (usually measured in degrees of an arc) through which the pendulum travels in passing from one extreme position to another, *e.g.*, from P to P′ (Fig. 34), is called in England *the amplitude of the vibration.*

To avoid any confusion we will here explain that in the following pages the motion of the pendulum, M, from P to P′ *and back* will be called *a vibration*, the time occupied in this motion will be called *the period of the vibration*, and the distance from P to P′ will be called *the amplitude of the vibration.*

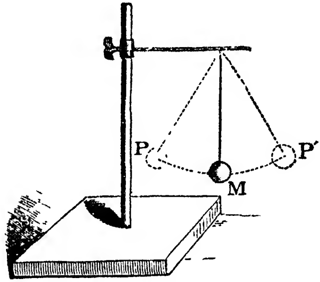


Fig 34.

Let us now take our stand by a field of waving corn; we shall see that the progress of each wave from one side of the field to the other can easily be observed, and that *though the ripened ears of corn make only a small vibration to and fro, the wave itself traverses the whole width of the field.* The ears of corn in this case behave like inverted pendulums, and their action illustrates the proposition we wish to establish, viz., that *there is a distinct difference to be observed between the onward motion of a wave itself, and the vibratory motion of the particles which at any moment constitute the wave.* In Fig. 34 above, the suspended balls move forwards in one direction, *and backwards in another*, whereas the motion of the so-called wave itself (*i.e.*, the motion translated), is in one direction only, viz., from left to right.

To obtain a clearer idea of this proposition, let us take up a position by the side of a river, and watch the pieces of wood floating down with the stream to the sea. Here we have the waters of the river actually moving forward in a certain definite direction, thus providing us with an instance of *the translation of matter;* for of course we regard the water particles as particles of matter. Here also we see that the translation of particles of one kind of matter may cause the translation with them of other particles of a different kind of matter, viz., *solid* particles of wood travelling upon *liquid* particles of water. Leaving the river's side we make our way now to the sea-side, and there occupy ourselves in watching the great waves rolling in towards the land. At some little distance from the beach we may notice a quantity of sea-weed dancing up and down upon the surface of the water, and if we narrowly observe it, we shall find that though it is ever in motion, now rising high upon the crest of a wave, and now sinking down into the depths of its trough, it still remains at about the same distance from us, neither advancing towards us nor receding from us. If now there was in the sea at this point a continual translation of matter, as there was in the river beside whose water we lately stood, it would seem that the sea-weed should be

carried along in a direction coinciding with that in which the water was moving; seeing, then, that the sea-weed does NOT change its position, we conclude that the water upon which it floats does not suffer any translation from one place to another, although it certainly is ever in motion, and although waves are most certainly continually traversing its surface.

It may easily be shown that an *up and down* motion of the particles of a body would cause the translation of a wave from one point to another, which amounts to showing that *a wave may be caused to move from one point to another through that body, by the vibratory motion of its particles, in a direction at right angles to that in which the wave proceeds.*

In the accompanying diagram (Fig. 35), let the rectangles aA, bB, cC, &c., represent the spaces through which the particles in these rectangles

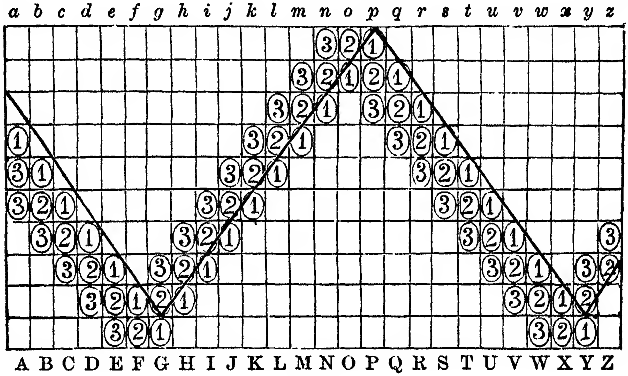


Fig. 35.

have power to move up and down, and let the circles numbered with a figure 1 represent the particles forming the surface of the wave whose crest is at p, and the lowest parts of whose depressions are at G and Y. Then it is clear that the particle at p is at the farthest limit of its excursion *upwards*, and that those at G and Y are at the farthest limit of their excursions *downwards*, and it is in harmony with this to suppose that the particles in the spaces A to F are all *descending*, those in the spaces H to O *ascending*, those from Q to X *descending*, while Z is also *ascending*. Under these circumstances the surface of the wave is represented by the thick line drawn through the particles numbered 1.

Let us now suppose that the particle at p begins to descend, and continues to do so till it has gained the space 2 below it; by this time the particle O has gained its highest position and now forms the crest of the wave, the whole surface of which is represented by the dotted shapes numbered 2.

Supposing now that the particle at P continues its downward course till it rests at 3, it is clear that the crest of the wave will then be at *n*, and that the circles numbered 3 will represent the surface of the wave at this moment.

Without giving this as an exact explanation of the manner in which a wave is actually propagated through a body, we may use it to show that *there are two distinct movements to be observed in wave motion*, viz., 1st, the onward motion of the wave itself (which is simply a translation of *motion*), and 2nd, the vibratory motion of the particles of the body through which the wave is propagated, this vibratory motion being really a translation of *matter* (viz., the individual particles of the body), alternately upwards and downwards through a limited space. It also serves to show that *a wave may be propagated in a certain given direction by the movements of particles of matter oscillating in a direction at right angles to that in which the resultant wave travels.*

And further it assists us to a right conception of what a wave is, viz., that it is simply the propagation of *a form* or *shape* (and therefore does not imply a translation of matter in the direction in which it is itself propagated).

Further, if we apply the above conception to a water-wave,* and then further conceive a chip of wood (or bit of sea-weed) so extremely small as to rest on one alone of the water particles represented in the figure, say *p*, then it is clear that such chip receiving its support solely from *p* must rise as *p* rises and sink as it sinks, and being (as we suppose) subject to no other influence than that exerted upon it by the water upon which it rests, cannot do otherwise than rise and fall with the water without suffering the least translation whatever, except such as is also experienced by *p*; and since we have supposed that *p* simply oscillates up and down in its own rectangle, it follows that the only effect of the wave upon the chip will be to cause it to dance up and down with the surface of the water upon which it rests.

And, once more, it is clear that while the particle at G (*i.e.*, at the lowest point in the trough of the wave) performs the journey to *g* and back, the whole wave will have travelled so far to the left as to bring in succession all the particles between Y and G to the lowest points of their respective excursions, thus causing the trough of the wave at Y to travel to G: this distance, viz., YG, is called *the wave-length*, and may be defined as *the distance travelled by the wave itself during a complete vibration of one of the particles of the body through which it travels.*

As above explained, the *period or time of vibration* is the time occupied by a vibrating particle in performing a complete vibration. Now, as we

* This idea of the manner in which a wave may be propagated does not pretend to scientific accuracy, though it serves its purpose well enough with young students.

shall see later on, a sound-wave travels through water at the rate of 4708 feet per second; if, then, we suppose that the bell which produces the sound makes 450 vibrations per second, it is clear that the first of 451 sound-waves will have travelled 4708 feet from the bell before the last one starts, so that at any moment there will be in these 4708 feet of water no less than 450 sound-waves: or, in other words, these 4708 feet of water will be carved out into 450 condensations, and an equal number of rarefactions all existing in the water at the same moment, each condensation with its accompanying rarefaction being the result of a single vibration of the sounding bell.

In this case, therefore, the *wave-length* of these sound-waves will be found by dividing 4708 feet by 450, and will thus be about $10\frac{1}{2}$ feet.

If $V =$ velocity of sound per second at a given temperature
$W =$ wave-length of a sounding body at that temperature; and
$N =$ number of vibrations executed per second by the sounding body;
then, it is evident that

$$\left.\begin{array}{l}(1.)\ V = W \times N \\[4pt] (2.)\ N = \dfrac{V}{W} \\[4pt] (3.)\ W = \dfrac{V}{N}\end{array}\right\}$$

So that if any two of the three quantities, V, W, N, be given, it is always possible to find the third.

If any confusion still exist in the mind concerning the difference between the motion of the wave and that of the particles through which it travels, let the student take a round ruler, and having placed it upon a table and covered it with a cloth, press the ruler forward between the table and the cloth. Then, although the cloth does not move forwards nor backwards, to the left nor to the right, but simply rises and falls as the ruler advances beneath it, yet there is a transference of a hump, or wave, from one side of the table to the other. The ruler here represents *the power* to which the wave motion is due, the rise and fall of the tablecloth illustrates the oscillation of the water particles in an upward and downward direction, and the passage of the hump across the table fitly represents the passage of a wave across water.*

That there is a distinct difference between the motion of a wave itself and that of the particles through which it travels, may be further seen from the fact, that earthquake waves have been observed to travel across a country at a rate which was a thousand times faster than that at which the earth particles moved, thus showing that not only is there a distinction to be made between the two motions, but also that they are often propagated at greatly different velocities.

It is worthy of remark here that the translation of the *motion* (viz.,

* This experiment conveys a more correct idea of the motion of the water particles than the last one did.

the onward propagation of the wave) is vastly more rapid than that of the translation of the *matter* (viz., the vibratory motion of the particles). In the same way the transmission of light and heat, which is supposed to be effected by the vibratory motions of the practically imponderable ether, is much more rapid than the rate of transmission of sound, which is in all probability due to the vibrations of the comparatively heavy particles of the atmosphere. These observed facts are in agreement with our every-day experience, which shows us that, other things being equal, those bodies move with the greatest velocity which have the least mass; this principle carried out in its fulness would lead us to suppose that, since all kinds of wave motion are produced by translations of *ponderable matter* resulting in a translation of a *perfectly imponderable* FORM, the rate of progress of this latter is necessarily infinitely more rapid than that of the former, a result, however, which must be modified by the fact that *the active causes of the two motions are not the same*, for the translation of the wave is clearly *the effect of an effect*, inasmuch as it is produced by the oscillatory motions of the vibrating particles, which oscillatory motions are produced by some disturbing cause, and it could scarcely be supposed that the oscillatory motion so produced should represent the entire effect of this disturbing cause, else the progress of the wave would be *infinitely* instead of *measurably* rapid.

It has been already remarked that sound differs from light and heat in that it is transmitted from place to place by vibrations of the particles of the atmosphere and other ponderable bodies, while light and heat are propagated by vibrations of the ether which interpenetrates those particles; it should here be added that whereas sound is the effect of vibrations performed *to and fro along the line* in which the wave travels, light and heat are transmitted by vibrations performed at right angles to the lines in which they travel.

12. A Sonorous Wave. There can be no doubt that the cause of sound is in every case *motion*. The act of hearing thus becomes one of appreciating those vibratory motions of the air particles which are communicated to the auditory apparatus of the ear, and are by it transmitted to the brain, where, of course, the sensation of hearing is experienced.

It now becomes necessary to examine more minutely the manner in which these sonorous waves are generated in, and propagated through, the atmosphere.

If we carefully smooth down the surface of a feather bed, and then plunge our hand deeply into it at any point (of course, without breaking its covering), we shall see it rise up all round our arm. Or if we press down heavily upon one end of it, we shall see it rise up in a heap at a spot where we are exerting no direct pressure at all. If now the feathers of the bed were endued with an elastic force, by reason of which they re-

covered their positions immediately we withdrew the pressure which had caused the uprising, we might—by continually restoring and then again continually removing this disturbing pressure—generate a kind of up and down vibratory motion among the feathers composing the bed. And this vibratory motion would ultimately be communicated to the whole of the bed.

Again, let ABCD represent a small cistern partly filled with water, and let it be supposed that it is possible to increase or diminish at will the distance, BC. If this distance be *diminished*, then it will be found that the force with which AB presses against the water (in its act of drawing nearer to CD) is sufficient to so compress the water that *it rises* to escape the pressure, thereby increasing the depth (though not the quantity) of the water. If, however, the distance between AB and CD were *increased* the water would *sink*, thus becoming less deep. And if it could be so arranged that the distance, BC, was being alternately increased and diminished, then there would be a continual *rise* and *fall* of the surface of the water, corresponding respectively to an *increase and a decrease* of the force with which AB was pressing the water against CD.

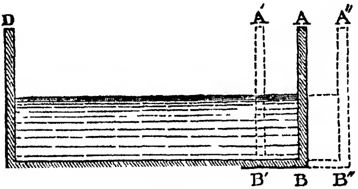


Fig. 36.

And if it could be further arranged that the rate at which AB approached CD was always greatest when in the position AB, then the force by which the water was being urged against CD would of course be greatest when AB was in that position on its journey towards CD; and if the velocity with which AB receded from CD was always greatest when it was passing this same position, then it is clear that the force with which the water sank in the cistern would always be greatest when AB crossed that spot on its journey towards A″B″.

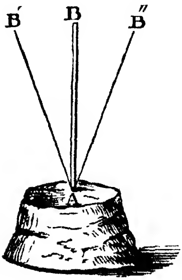


Fig. 37.

Let us now take the rod, AB, and secure it firmly in a block of wood; then pull it to the position, AB′, and then release the end B′. It will at once begin, and will then continue to oscillate backwards and forwards from the position AB′ to AB″, and the rate or velocity with which it moves will increase as it leaves the position AB′ until it is at AB, when its velocity will be at its maximum; it will then decrease

until it reaches AB″ when it will be NIL. Immediately afterwards it will set out on its return journey, passing AB again at a maximum speed, and then diminishing in velocity till its motion becomes for a moment once more NIL at AB′.

If any proof that this is the case be required, the student has but to perform the experiment, and he will see that while the rod is oscillating, the space between the two positions, AB′ and AB″, seems bounded at these two places by lines which are tolerably sharply defined, while at AB there seems scarcely anything visible (see fig. 38).

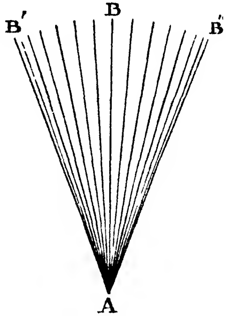


Fig. 38.

The explanation of this is, that as the motion of the rod is for a moment NIL at AB′ and AB″, there is time for the eye to observe it, but as its velocity increases towards AB the eye obtains a less and less distinct impression of it, and at AB perhaps does not actually observe it at all.

Now a tuning-fork in the act of sounding vibrates just in the same way; its greatest velocity always coincides with the moment it is passing the position AB.

Now let us suppose that this tuning-fork is vibrating in an open room, and let us consider the effect of its motion upon the air surrounding it. As the prong, AB, moves forward from the position AB′ towards AB″, it forces the air before it, thus tending to crowd together the particles of air which lie before it, and it is clear that the more rapidly AB advances towards AB″, the more dense will this crowding of particles at any moment be. Consequently, this crowding will be most dense when AB is crossing the position AB, because, as stated above, the velocity with which the prong moves is then at its maximum. But we know that air possesses *elasticity*, in other words, it exhibits a disinclination to be crowded into a smaller space, or rather, it has a perpetual tendency to occupy any space open to it, however large; consequently, the particles of air crowded together by the forward motion of AB exert in their struggle for room a force upon all things surrounding them. But this force, almost vainly exerted against AB, is effectual as exerted upon the air particles lying beyond those in the immediate neighbourhood of AB, for these more distant particles being less densely packed than the former, are not so active in their struggles for room (in other words, do not possess so great an elasticity), and consequently suffer themselves to be crowded together by the greater exertions

Fig. 39.

of their neighbours. These crowded particles, in the same way, pass on the crowding to particles lying still further from AB, and thus a *crowding* or *condensation* of air particles is propagated as a pulse or wave through the air.

But our prong, AB, having passed the position, AB, begins now to travel more slowly, and as a consequence, the condensation produced by its motion among the air particles becomes gradually less and less, until at last the prong, AB, having reached AB″, stops for a moment, and then of course there is no further condensation produced among the air particles, though the condensation already produced continues its course through the portions of the atmosphere lying more and more remote from AB. The accompanying diagram will show the form of this condensation.

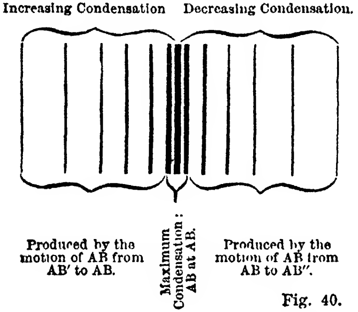


Fig. 40.

But the prong, AB, scarcely attains the position, AB″, before it begins to return again to its former position, and it is evident that in this backward journey it must leave momentarily behind it a space unoccupied by air, though on every side (except that on which AB is) surrounded by air. Into the space thus left unoccupied the surrounding air will, by reason of its elasticity, at once expand; thus, of course, being more rarified. It is also evident that since the rate at which AB moves continually increases as it proceeds from AB″ to AB, this rarefaction of the air to the right of AB must continually increase till the point at which the velocity of the prong is greatest is reached, and that after that the rarefaction, like the velocity, will continually decrease till the prong once more attains the position AB′.

It thus becomes clear that one effect of the vibration of a tuning-fork is the transmission through the air of condensations and rarefactions regularly succeeding each other. It is also evident that *the propagation of these condensations is the result of the elasticity of the air.*

It need scarcely be added that these condensations and rarefactions may be *produced* by *any body* vibrating in the air, and may be *propagated* by *any medium* possessing the requisite elasticity; also, that according as the maximum speed of the vibrating body is greater or less compared with its minimum speed, so the difference between the greatest condensation and the greatest rarefaction will also be greater or less, or, which comes to the same thing, according as the shock communicated to the air is more or less *abrupt*, so the pulsations propagated through the

air will be more or less distinct, and consequently the sound produced by these pulsations will be more or less audible and distinct.

So far we have been able to show that sound is the effect of waves (each consisting of a condensation and a rarefaction) generated by bodies vibrating in the air, and propagated through the air by reason of the elasticity of that medium; also, that although these waves may be produced by *any* body vibrating in any manner in the air, it is requisite that these vibrations shall be sufficiently rapid to communicate to the air a certain sharpness of shock, if the effect is to be a sound distinguishable by the ear.

But although the vibration of a column of air (viz., that contained in the passage leading inwards to the drum of the ear) is the instrument chosen by nature for actually giving up the sound-waves to the auditory apparatus of the ear, it must not be for a moment supposed that such waves cannot be transmitted by any medium other than the air, for we have already shown that sound can and does travel through other gases, and also through liquids and solids. It has also been mentioned that the rate of its transmission through different media is not uniform. It now becomes necessary to deal with this matter a little more fully.

We have shown, in previous pages, that gases admit of great compression, in other words, that they can be forced by pressure to occupy a space, or *volume*, which is continually less and less as the pressure exerted upon them is made continually greater and greater. We have also defined the elasticity of these gaseous bodies as *that power by which they resist compression when subject to it, and by virtue of which they tend to recover their original dimensions, and, in fact, do so recover those dimensions as soon as the compressing force is withdrawn.* Now, experiments show most clearly that, although all gases are comparatively easily compressed, their elasticity being therefore in the same degree small, all liquids present a very effective resistance to compression, being for that reason called *the incompressible fluids;* the elasticity of liquids is thus shown to be much greater than that of gases.

Experiments also show that the compressibility of solids is much smaller, as a rule, than that of liquids; it follows that *the elasticity of solids is greater than that of liquids.*

Viewing matter, then, with regard to its elasticity alone, it becomes evident that the greater the elasticity of a liquid the more nearly it will resemble a solid, and the greater the elasticity of a gas the more *it* will, in this particular, resemble a solid, so that we may, for a moment, regard solids, liquids, and gases as being but three different manifestations (or appearances) of one matter, and called by these three different names simply to show that this matter possesses, under different circumstances, different powers of resisting compression.

Let us now take means to give a blow of a certain force to the end,

A, of the rod, AB, whose other end, B, touches the ball, C, suspended by a thread from D. Then the effect of the blow delivered at A will be shown by the portion of the arc, CE, over which the ball, C, will be compelled to travel; and it may be added that the force applied to A by the blow will be delivered to C almost immediately and practically undiminished.

Let us now remove that portion of the rod, AB, which is marked FG, and let us then fill the cistern with a fluid, say water. Then let a blow, exactly equal in power to the first one, be delivered to A; it will then be found that the motion communicated to C does not cause it to fly off so far, nor with such speed as in the former case, the reason being that the force has in this case to be propagated, in one part of its course, through a liquid which may for our present purpose be regarded as a solid of inferior elasticity, or, in other words, a solid possessing but an imperfect power of resisting compression, in consequence of which the shock communicated to it at F becomes for a moment partly occupied in

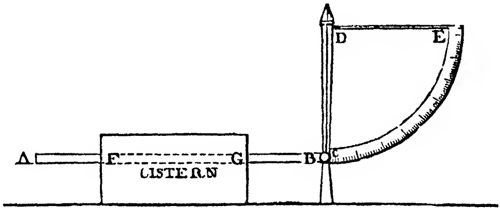


Fig. 41.

forcing the contained liquid into a smaller space, and although this force so occupied does again manifest itself in a pressure exerted everywhere upon the inside of the cistern tending to burst the walls of the cistern, *it occupies time* in this effort, and thus makes the transmission of the force more sluggish than would be the case if the elasticity of the water were greater.

If the water be now removed and the cistern be filled with air, the effect of a blow exactly similar to the former one delivered at A would be practically imperceptible, the reason, of course, being, the very slight elasticity of the air as compared with water and wood. Here, again, air may be regarded as a solid of infinitely small elasticity.

Let us now suppose a tuning-fork in the act of sounding in air; its vibrations to and fro impart a number of successive blows to the air in its immediate neighbourhood. But we have seen above that a blow delivered to a solid is by it passed on almost immediately, and that, according as the state of solidity is more and more departed from, the power of so com-

municating blows with sharpness becomes more and more feeble, consequently the blows of the tuning-fork travel but slowly through the air; but they would travel much more quickly through a liquid, and more quickly still through a solid.

Once again, it has been already stated that bodies may be changed from the state of solids to that of liquids by the application of heat, and that such liquids may be compelled to assume the state of gases if sufficient heat be applied. Experiments will be given further on to prove that, with few exceptions, a pound (or any given weight) of a solid requires more room when heat is applied to it than it did before such heat was applied, in a word, that the effect of the application of heat to any body —solid, liquid, or gaseous—is to generate in that body a desire, so to speak, an almost irresistible desire to occupy more room, *e.g.*, a pound of water when changed to steam occupies about 1800 times as much room as it did in the form of water. Now, we cannot suppose that each tiny particle of water has, so to speak, *swelled* out itself to 1800 times its former size, for if so, there must be a cavity or a great number of cavities somewhere in it. It is impossible to imagine that any portion of matter, however minute indeed, could occupy more than a definite amount of space; its bounding surface may indeed be greatly enlarged, but that can only take place when there is an increased amount of space remaining unoccupied between its component particles. Seeing, then, that we are forbidden to suppose that the ultimate particles of this pound of water swell out themselves, we have nothing left us but to assume that they are driven farther and farther apart as there is applied to them a greater and greater force of heat. But if they are so driven farther and farther apart, it at once becomes obvious that the body which they compose more and more departs from the idea of our rod, AB, in the last diagram; in other words, it becomes less and less a perfect solid, and more and more approximates to the idea of a chain of disconnected solids.

Now, the more closely the particles of a body are packed together the greater we say is the DENSITY of that body; it follows that under ordinary circumstances *the density of a body decreases as its temperature increases.*

We will now in fancy take a strong vessel, completely fill it with water, hermetically close it, and then apply heat to it. Such an experiment would be a most dangerous one, for the following reasons. At the temperature at which the water was when put into the vessel it was content to occupy just that space which was afforded by the inside of the vessel; but as soon as heat is applied it is no longer satisfied with that amount of space, but each particle of water struggles fiercely to increase the distance between it and its neighbours; but these neighbours, actuated by the same desire of repelling those around them, as fiercely resist the pressure put upon them by it. If we fancy them endued, each

and all, with hands and arms, then we at once conjure up to our minds all these watery particles engaged in a fierce struggle, in which each places his hands upon his neighbour's shoulders and desperately endeavours to repel him to a distance. They now form a firmly connected mass, an actually connected body of active individuals. These hands and arms do not, of course, belong to the watery particles under consideration, but they well represent the elasticity which is active between them. We can carry our fancy yet further, and imagine some kind of push to be communicated to one of the contending atoms; this push will be more or less promptly communicated by the atom which first received it to the next atom, according as the stiffness of his arms which are engaged in repelling that atom is more or less great, which being translated is this: *—the waves of sound travel from atom to atom of a body with a greater or less velocity, according as the elasticity acting between these atoms is greater or less, the density being the same.*

It now becomes necessary to make a most important distinction. It may perhaps be at once assumed that, instead of supposing, as above, the arms of the watery particles to represent the elasticity of the air, we might imagine a number of new particles interposed between the original ones, so that no one of the original particles could move without moving some of these newly-interposed particles, and then it might be argued that, the more closely these new particles were packed together between the original ones, the more quickly and more completely a wave motion would be transmitted through the body; in a word, *we might expect that by increasing the density of a body we should thereby increase the rate at which sound would travel through it.* But this is not so, for we must remember that every body, however small, has a tendency when at rest to continue at rest, and to overcome this *inertia*, as it is called, the expenditure of a certain amount of force is required. Accordingly, then, as we increase the density of a body, or, in other words, according as we pack more particles into any given space, so the work to be done in setting them in motion increases. We may illustrate this way: let these boys in dark clothing, whose arms hang by their sides, represent a row of particles of a body; now, if a slight push be given *f* this will in no way effect *a*, because *f* will not be sufficiently disturbed to knock against *e*. This represents the state of a very inelastic body.

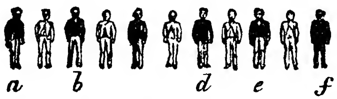


Fig. 42.

Let now each boy place his arms loosely upon his neighbour's shoulders, then a push of the same force as the former being communicated to *f*, will be by it languidly given up to *e*, and more languidly given up again to *d*, and so may be lost before it reaches *a*, having been dissipated in

overcoming the inertia of the bodies of these boys. Thus, it is clear that the more we tighten the hold these boys have of one another (or the more rigidly each holds the one before him), the more quickly the push communicated to f will be passed on to a. Yet it will not reach a undiminished in force, because some part of its energy must of necessity be absorbed in overcoming the inertia of the bodies a, b, c, d, e, f. If now we could introduce the boys in lighter clothing without increasing the stiffness with which each held the one before him (*i.e.*, if we could increase the *density* without increasing the *elasticity* of a body), it is clear we should increase the obstructions to the progress of the wave of motion, which would thus occupy longer in travelling from f to a than it would have done before the introduction of these new boys, which goes to show that *by increasing the density of a body, without increasing its elasticity, we diminish the rate at which sound waves pass through that body.* Experiments go to show, that *the velocity with which sound travels through a body is directly proportional to the square root of the elasticity of that body, and inversely proportional to the square root of its density.*

13. Influence of Temperature upon the velocity of a Sound Wave. —When the density of the air increases, the fact is notified by a rise in the level of the mercury in the *barometer;* an increase in the temperature of the air is similarly proclaimed by a rise in the level of the mercury in a *thermometer.*

Now it has been found that the velocity with which sound travels through air is *not* affected by changes in the *barometer* reading, but that it is increased by a rise in the *thermometer.* Let us see why this is.

An increase of density is always accompanied by an increase of elasticity, *when the temperature remains unchanged,* consequently an increase of density is not, as one might at first expect, accompanied by a decrease in the velocity of the sound wave. But an increase of temperature is always accompanied by an increase in the elasticity of a body, and consequently, if the density of a body remain unaltered when heat is applied, there is at once an increase in the velocity with which the sound wave travels through that body, because the elasticity is increased, without a corresponding increase in the density.

Consequently, although the velocity of sound through air at a temperature of 0°C is about 1090 feet per second, it increases as the temperature rises, and diminishes as the temperature falls, and experiments go to show that the rate of this increase is about 2 feet for every degree centigrade.

14. The Relation between the Amplitude of the Vibration and the Intensity of the Sound.—In Fig. 43 let AC and AD represent the extreme positions of the vibrating pendulum, AB; then the distance, CD, is called the AMPLITUDE of the vibrations of this pendulum.

In the same way B'B'' of Fig. 44 represents the *amplitude* of the vibrating rod, AB.

Now if the amplitude of the vibrations in either of these cases, say the latter, be doubled, let us see what will happen.

(1.) It is clear that if d represent the amplitude of the original vibration, then $2\,d$ will represent the amplitude of that vibration when doubled.

(2.) We know that with any given pendulum, or vibrating rod, *the time occupied by it in performing a complete vibration is altogether independent of the width of its amplitude;* in other words, whether d be great or small the pendulum occupies the same time in moving from C to D while vibrating. It follows, then, that if $2\,d$ be traversed in the same

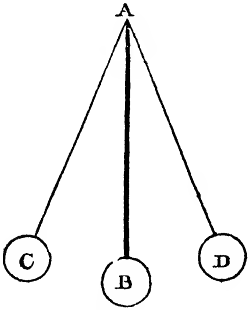


Fig. 43.

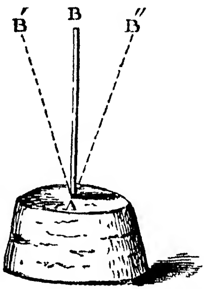


Fig. 44.

time as d, the mean speed of the moving body must in the former case be *double* that in the latter.

Now if a certain amount of energy be required to cause a body to travel over the distance, d, it is evident that *double* that energy will be required to cause it to travel over the distance $2\,d$; and again, if this double distance is to be got over in the same time as the original distance was completed, then the double force already shown to be necessary must be again doubled, so that we may say *the energy required to cause a pendulum to vibrate with a certain amplitude is four times the energy which would be sufficient to make it perform vibrations of half that amplitude.* In the same way, if the amplitude were increased to *three*fold, the requisite energy must be increased to *nine*fold; in other and more general terms, *the energy of the vibrating body increases with the square of the amplitude.*

(3.) As the vibrating body moves forward or backward in its course there is evidently a corresponding change in the nature of the energy

causing its vibrations. At AC or at AD the force is clearly all *potential*, or stored-up force, because in those positions the vibrating body comes momentarily to rest. At AB, however, it is evidently all *kinetic* or active energy; and at positions intermediate to AB and AC, or AB and AD, the energy is partly kinetic and partly potential.

In every position, however, the absolute amount of energy—whether *potential* or *kinetic*, or partly both, is the same; let us see what is the result of this.

To begin with, it is evident that the vibrations of the air particles must exactly resemble the vibrations of the tuning-fork (or other vibrating body) which has set them in oscillation. But the movements of such a tuning-fork exactly resemble those of the pendulum above described; consequently the movements of the air particles exactly correspond to those of a vibrating pendulum. We come, then, at last, to this, that the energy (potential or otherwise) of each air particle as it oscillates under the influence of a sound wave varies as the square of the amplitude of the vibrations of the sounding body; in other words, if the amplitude of the vibrations of a sounding body be *doubled*, the energy thereby imparted to the particles of the air among which the body is vibrating is increased *fourfold*, if the amplitude be *trebled*, the energy generated is thereby rendered *ninefold*, &c. &c.

It follows, then, that the effect produced upon a person's ear by the impinging upon it of a sound wave varies directly as the square of the amplitude of the vibration of the surrounding body.

But the greater the force with which the drum of the ear is agitated the louder is the sound, therefore we say that *the intensity of the sound increases with the square of the amplitude of the sounding body.*

This will be a convenient place for remarking that no confusion must be allowed to linger in the mind concerning the meaning of the terms VELOCITY, INTENSITY, and AMPLITUDE. As already explained, **the velocity** of a sound wave is the speed with which sound waves travel from point to point of space, and depends upon the density and elasticity of the *propagating* medium, but is independent* of the rate of vibration of the *generating* body. **The Intensity** of a sound is its loudness, and, unlike the velocity, depends entirely upon *the amplitude* of the vibrations of the sounding body, which amplitude may be taken to mean the distance travelled over by a vibrating body in its passages from one of its extreme positions to another.

15. The Law of Inverse Squares.

(1.) *In its Application to Sound.*—We have already shown that the

* Not QUITE independent, for there is reason to suppose that loud sounds travel quicker than softer ones.

intensity of a sound varies as the square of the amplitude of the vibrations which give rise to it, and that this fact results from this other fact, that *the energy of an air particle executing simple vibrations in obedience to forces of elasticity, varies as the square of the amplitude of its excursions.*

Now let the line AB be divided into *four* equal parts by the points D, C, E, and let the circle D represent the surface of a sphere, having AD as its radius, while the circles C and E similarly represent the surfaces of spheres having AC and AE respectively as radii. Then we know by geometry that *the surfaces of these several spheres are to one another as the squares of their radii;* thus we have the surface of the sphere D, *one-fourth* of that of the sphere C, *one-ninth* of that of the sphere E, and *one-sixteenth* of that of the sphere B.

Let us now suppose that the lines AD, AC, AE, and AB, represent the distance travelled by a sound wave, starting from A in *one*, *two*, *three*, and *four* seconds respectively. Then at the end of one second we shall have the disturbing force, which initiated the sound by vibrations at A, expending itself in causing all the air particles lying in the surface of the sphere D to oscillate; at the end of another second we find this same disturbing force occupying itself in setting up oscillations among the air particles of the sphere C. But the number of particles here is four times greater than those in the surface of the sphere D; consequently, the initial energy at this point, C, being distributed over four times as many particles as at D, the effect upon each individual particle at C is one-fourth only of that at D, so that *the energy of a particle vibrating at any given distance from the disturbing body is four times greater than at double that distance.*

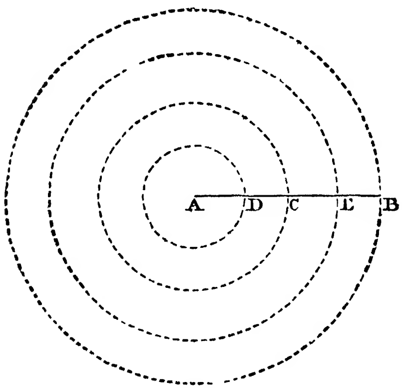


Fig 45.

In the same way it is shown that the energy of a particle vibrating in the surface of the sphere E is *one-ninth,* and in the surface of B *one-sixteenth* of that of a similar particle vibrating at D; in general terms, *the energy of any of these particles executing simple vibrations in obedience to*

forces of elasticity varies inversely as the square of their distance from the disturbing body.

But it has been already shown that the intensity of a sound varies directly as the energy with which the tympanic membrane of the ear is struck ; it follows, then, that *the intensity of a sound proceeding from a uniformly sounding body varies inversely as the square of the distance from that body.*

This proposition, derived from theoretical considerations, is abundantly confirmed by experiments.

It will now occur to the reader to ask what becomes of a sound at last? Does it go on gradually diminishing in loudness for ever and ever, or, at least, till it reaches the outmost limits of our atmosphere, or does it become somehow dissipated in its passage from layer to layer of the surrounding atmosphere? *The truth is, it does suffer dissipation;* for it is by friction that each layer of air is enabled to set in vibration those other layers lying beyond it ; but friction always generates heat, and thus we get the sonorous energy dissipated by its gradual conversion into heat. As a fact, then, the intensity of sound diminishes somewhat more rapidly than is indicated by the above law of squares, and *its final extinction is the result of the conversion of the whole of its energy into heat.*

(2.) *In its Application to Light.*—The light proceeding from any luminous body, say a candle, may at any moment be regarded as a certain definite force whose action is momentarily spreading itself over larger and larger areas, just as we have shown the sphere of action of the sound-producing force to spread. But the sensation of light, like that of sound, is due to the effect which this motion produces on our nerves ; the consequence is, that if the effect of the light-producing force diminishes, our sensation of "*light*" must also diminish, and that in the same proportion.

But this light-producing force evidently diminishes according to that *law of inverse squares* which governs the rate of diminution of the sound-producing force ; consequently, *light*, like *sound*, varies inversely as the square of the distance from the body which produces it.

According to this law, then, it is clear that one candle at a distance of one foot has the same illuminating power as four candles two feet distant, nine candles at three feet distance, &c. &c. To prove this, take a piece of white paper, and make a faint grease spot on it with a little stearine, then stretch the paper on the frame of a slate and place it in an upright position on a table ; at a certain distance on one side of the frame place a lighted candle, and on the other side, at twice the distance from the frame, place *four* similar lighted candles ; the grease spot is then invisible because it is equally illumined on both sides. This apparatus is sometimes called *Bunsen's Photometer.*

Photometers are instruments used to measure the illuminating powers

of such artificial lights as candles, lamps, gas burners, &c. The experiment called the *Shadow Test** also serves the same purpose.

In the accompanying figure the shadows cast by the rod, R, are caught on a white screen—the frame and paper described under Bunsen's photometer will do—the shadow, C, is evidently more heavy than D, consequently the lamp, A, which casts the shadow, C, must be removed farther from the screen till both shadows become of equal heaviness. If it should then be found on measurement that they stood three feet from the

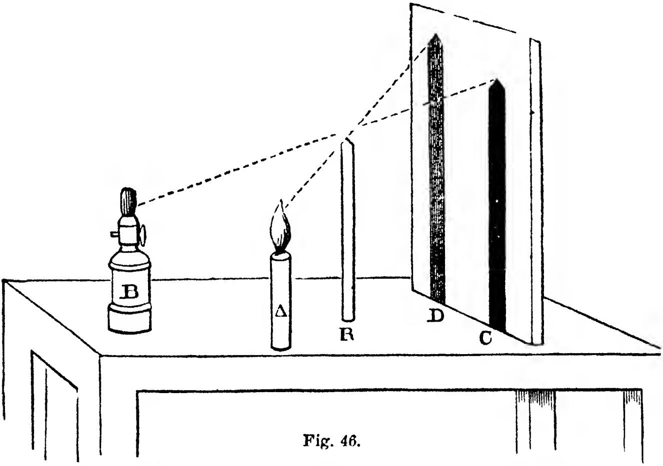


Fig. 46.

screen, while the weaker stood but two feet from it, we should calculate the relative illuminating powers of these lights according to the rule of inverse squares, thus—

$$\frac{\text{The power of the lamp}}{\text{The power of the candle}} = \frac{\text{the square of the distance of the candle}}{\text{the square of the distance of the lamp}}$$

$$= \frac{3 \text{ feet} \times 3 \text{ feet.}}{2 \text{ feet} \times 2 \text{ feet.}}$$

$$= \frac{9 \text{ square feet.}}{4 \text{ square feet.}}$$

$$= \frac{9}{4}$$

Therefore, the illuminating power of the lamp = $2\frac{1}{4}$ times that of the candle.

N.B.—The intensity of radiant heat, also, has been shown to vary inversely as the square of the distance from the heat-giving body.

---

* The instrument used for this purpose is often called "*Rumford's Photometer.*"

16. Experimental Determination of Velocity of Sound and of Light.

(1.) *The Velocity of Sound* through air is easily determined as follows: One person standing at B fires off a gun: the report and the flash both start at the same moment towards another person standing at A. Now, the velocity of light is so great that in this case we may neglect altogether the time occupied by the flash in proceeding from B to A, and may therefore regard it as observed at A instantaneously with its production at B. But the sound travels much slower, and consequently arrives at A some seconds after the person there observes the flash; if the report arrived at A *five* seconds after the flash, then it would be concluded that the sound occupied those *five* seconds in passing from B to A, and if the distance BA be 5500 feet, the velocity of the sound in this case would be $\left[\frac{5500}{5}\text{ feet, } i.e.\right]$ 1100 feet per second.

A . . . . B

Actual experiments show that *the velocity of sound in air at the freezing temperature is* 1090 *feet* per second, and that this velocity increases with the temperature (§ 13) at the rate of 2 feet for every degree centigrade.

Distances can be calculated by means of the known velocity of sound: *e.g.*, suppose it is observed on a frosty morning that the number of seconds which elapse between the discharge of a distant cannon and the arrival of the sound is $3\frac{1}{2}$; we calculate that the cannon is, therefore, (1090 ft. $\times 3\frac{1}{2} =$) 3815 feet distant.

The distance of a thundercloud may also be similarly calculated, for, as the report of the thunder and the flash of the lightning both start from the cloud at the same moment, the distance of the cloud will be found by multiplying the velocity of the sound by the number of seconds which elapse between the arrival of the lightning-flash and that of the thunderclap which follows it.

But sound travels also through liquids and solids as well as through air and other gases, and the general expression for finding its velocity is

$$V = \sqrt{\frac{E}{D}}$$

when V = the velocity of the sound (or other) wave,
E = the elasticity of the medium through which it travels in any particular case,
D = the density of that medium.

Now it is found by experiment that the value of V when sound travels through water is four times its value when sound travels through air; in other words, sound travels four times quicker through water than through air. Therefore if

V = the velocity of sound in air,
4V = its velocity through water.

Before proceeding further it will perhaps be useful for young students if we explain that the fraction $\frac{E}{D}$ represents $E \div D$, or, *the number of times E contains D*, or, *the relation existing between E and D as regards magnitude.*

Now, since

$$V = \sqrt{\frac{\text{the elasticity of air}}{\text{the density of air,}}} \text{ we have}$$

$$V^2 = \frac{\text{the elasticity of air}}{\text{the density of air}}$$

$$\therefore 16\ V^2 = \frac{\text{the elasticity of air}}{\text{the density of air.}} \times 16 \ldots\ldots\ldots(a)$$

And, again, since

$$4\ V = \sqrt{\frac{\text{the elasticity of water}}{\text{the density of water}}}$$

$$16\ V^2 = \frac{\text{the elasticity of water}}{\text{the density of water}} \ldots\ldots\ldots\ldots(b).$$

Therefore, combining (a) and (b) we find that

$$\frac{\text{the elasticity of air}}{\text{the density of air}} \times 16 = \frac{\text{the elasticity of water}}{\text{the density of water.}}$$

In other words,

> "*The relation between the elasticity and the density of air*" *is one-sixteenth of* "*the relation between he elasticity and density of water.*"

The manner in which the velocity of sound through water has been determined experimentally is as follows :—

Two boats were moored at a known distance on the lake of Geneva, from one of which a bell was suspended in the water. The hammer with which this bell was struck was so contrived that at the moment of striking the bell it ignited a quantity of gunpowder, the flash from which could be observed by the person in the other boat. This person held to his ear the mouth of an ear-trumpet (§ 57) whose bell was immersed in the water; he could thus both listen for the sound which was travelling through the water and at the same time watch for the explosion of the gunpowder; in this way he could measure the time required for the passage of the sound from the one boat to the other through the water. In this way the velocity was estimated to be 4708 feet per second.

Of course, different liquids convey sound with different velocities, but the velocity is always in accordance with the formula $V = \sqrt{\frac{E}{D}}$

The velocity of the transmission of sound through solids also conforms to the same law; but, as the value of the expression $\frac{E}{D}$ is nearly always greater for a solid than for a liquid or a gas, it follows that the velocity

with which sound travels through solids is greater in almost every case than that with which it travels through liquids and gases.

Experimental proofs of this are the following :—

(1.) The experiment shown in Fig. 31.

(2.) It has been found that when a bell was struck once at one end of a long iron tube two sounds were heard from the bell, one of which was conveyed by the solid substance of the tube,—this one arrived first,—and the other of which was conveyed by the air contained in the tube. If the tube had been a very long one, and had been partly filled with water, it would have been possible to hear three sounds proceeding from the bell in this case, the first to arrive being that brought by the iron of the tube, the second, that brought by the water, and the third, that transmitted by the air.

(3.) A person standing near a rock which is being blasted, may in a similar way often hear two reports from one explosion.

(2.) *The Velocity of Light* was determined as follows :—

In the accompanying figure let J represent the planet Jupiter, and E the earth, both moving in their orbits in the direction indicated by the arrows.

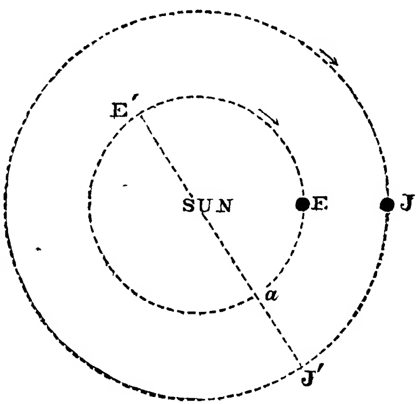


Fig. 47.

The planet Jupiter has four satellites, of which one is nearer the planet than the others, and it is observed that this one is continually undergoing eclipse, the period which elapses between any two successive eclipses being about 42 hrs. 28′ 35″. Exact observation, however, shows that the period which elapses between successive eclipses varies with the position of the earth with regard to Jupiter, being shorter by 16′ 26″ when the earth and Jupiter are closest together, as at E and J, than when they are farthest apart, as at E^1 and J^1. But the difference between the distances E, J, and E^1, J^1, is evidently equal to the diameter of the earth's orbit (*i.e.*, of the circle EE^1), it has therefore been sup-

posed that the 16′ 26″ is the exact time occupied by the light reflected from Jupiter in passing across the earth's orbit, *i.e.*, from a to E^1, *i.e.*, a distance of about 183,000,000 miles.

But if light travel 183,000,000 miles in 16′ 26″, *i.e.*, in 986 seconds, its *velocity per second* $= \frac{183,000,000}{986}$ miles = about 185,500 miles.

17. The Physical difference between Music and Noise.

That part of our organ of hearing which exists as a kind of appendage to the head, and which is usually called *the ear*, is in reality not the ear, nor indeed an essential portion of that organ. Its office is simply to collect the waves of sound which fall upon it, and then to pass them into the passage which leads into the interior of the head; at the end of this passage is a cavity called the tympanum, the entrance to which is stopped by a thin kind of membrane called *the tympanic membrane*. The vibrations which the particles of the atmosphere are executing in obedience to impulses received from a sounding body, are received upon this membrane, and by it transmitted towards the brain, and there they excite the sensation we call *Sound*.

Now any body vibrating in air, must necessarily tend to impress its vibrations upon the particles of the air surrounding it; if the vibrations of this body have a great amplitude, so will the vibrations imparted to the tympanic membrane likewise have a great amplitude; if the vibrations of the body be rapid, so will those impressed upon the tympanic membrane likewise be rapid; if the former be less frequent, so will also the latter be. It thus comes about that the vibratory motions of a sounding body exactly represent the state into which the tympanic membrane is thrown when the vibrations of the sounding body reach it; *e.g.*, if the sounding body be violently and irregularly agitated, violent and irregular will be the vibrations into which the tympanic membrane is thrown, and violent and irregular will therefore be the impressions produced upon the brain. Under these circumstances *there will be a want of smoothness and evenness and regularity in the sensation experienced by the brain*, in other words, a NOISE will be observed by the brain, and not a musical SOUND.

When the brain is thus agitated by the reception of numerous and conflicting impulses, it becomes in a manner bewildered and unable clearly to distinguish any one of the numerous impressions which crowd themselves upon it. In this confused state it is conscious of a NOISE, and not of a musical SOUND.

Again, the shock received may be, roughly speaking, instantaneous, and may be dissipated before the ear has time to estimate it; in this case, also, the effect produced is a NOISE, and not a musical SOUND.

The chief, and in fact, "*the only condition necessary to the production of a musical sound is, that the pulses should succeed each other in the same interval of time.*"—(*Tyndall.*)

If there be no succession of shocks, as when we hear the report of a cannon, or, *if there be an irregularity in the rate at which these shocks succeed each other*, as when we hear the wheel of a cart grinding against the paving, then a noise and not a sound, is the effect.

But it will at once be asked, *How is it, then, that every body in a state of uniform vibration does not produce a sound?* How is it that the continual ticking of a clock, or a watch, does not produce a musical note? and why is not music produced by the regularly recurring clickings of machinery? The answer is, that in order to produce upon the brain the sensation called a musical note, there must not only be a *regular*, but *a very frequently recurring* succession of the same impulses communicated to the brain. All people are not alike with respect to the number of vibrations requisite to produce in them the sensation of sound; the rapidity of the vibrations may be either too great or too small to be appreciated by the ear of any particular individual, though it may be clearly appreciable by other differently constituted ears.

18. Different methods of producing Musical Sounds.—Any body which is capable of being thrown into periodic vibrations, is capable of producing in us the sensation of sound. As a rule, this effect is produced upon us by the vibrations of the air surrounding us, so that we may say that any means by the use of which the particles of the atmosphere may be thrown into vibratory motion, become a means whereby sound may be produced.

Thus, for example, a tuning-fork, by its rapid and periodic oscillations, impresses upon the atmosphere surrounding it a system of oscillations in frequency and amplitude precisely similar to those executed by itself. These oscillatory movements being communicated to the brain result in the production of a musical sound.

Another method of producing sounds is by causing a number of *tappings*, or of *puffs*, to succeed each other with great rapidity. A musical sound has been produced by drawing a knife blade across the serrated edge of a coin; in this case the sound was the result of the blending together of the successive taps produced by the contact of the blade with the little irregularities forming the serrations upon the edge of the coin.

Sounds are, however, more easily produced by holding a piece of rather stiff cardboard against the edge of a revolving toothed wheel.

There is a curious and instructive method of producing sound, however, which is worthy of special mention. It is this: Take two small pieces of

lead, and fix them firmly in a vice in the manner shown in the accompanying figure. (See Fig. 48.) Then take a common fire-shovel, heat it, and then having balanced it upon the two pieces of lead, give it a tilt on one side, thus setting it in motion like a see-saw.

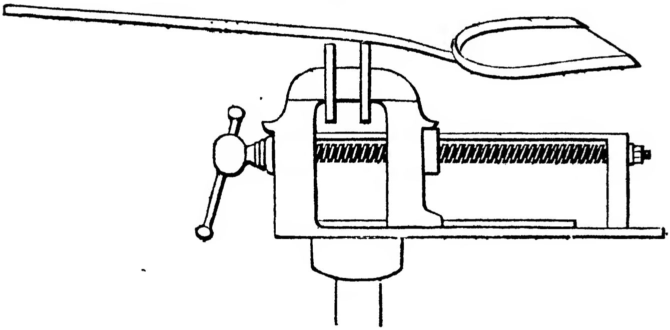


Fig. 48.

It will be found that a sound is produced by the shovel, which sound is thus accounted for. As soon as the shovel, which is hot, touches one of the pieces of lead, that piece of lead expands and swells upwards by reason of the heat received from the shovel; the shovel is consequently tilted up on that side, and therefore at once falls upon the other side, and endeavours to rest itself upon the other piece of lead. But this piece of lead behaves in its turn just as the other did, and immediately repels the shovel, which thus, by its motions backwards and forwards, throws the surrounding air into the series of waves necessary to the production of sound.

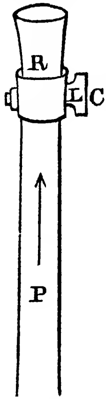


Fig. 49.

As mentioned above, sound is also produced by PUFFS. If we fancy a stream of air forced up through the pipe, P, in the direction of the arrow, then it is clear that if means were taken to open and shut the stop-cock, C, a great number of times per second, the effect must be a rapid succession of *puffs* produced at R, and the ultimate effect would be the production of a sound of a pitch higher or lower according as the puffs succeeded each other with more or less rapidity.

In producing sounds by this means, it is obvious that a great difficulty would be found in opening and shutting the stop-cock with a

rapidity sufficient to produce a sound. This might be partly overcome by making L of the stop-cock circular, and attaching a band to it, and then causing it to revolve by connecting it with a whirling table (Fig. 50).

A much better arrangement, however, is the following:

Let the pipe, P (Fig. 51), be brought to a small aperture, and caused to emit a continuous stream of air, and let the point F be placed over one of a series of perforations in the disc, CD, and let this disc be caused to revolve by connecting it with a whirling table. Then as the disc revolves the whole circle of perforations near its circumference come one by one beneath F, and consequently a whole series of puffs is produced, and these puffs follow each other more or less rapidly, according as the rate at which the disc revolves is greater or less. *The consequence is, a sound of higher or lower pitch according as the rate of the rotation of the disc is greater or less;* thus again confirming our previous remark that the *pitch* of a sound depends upon the number of (vibrations or) successive impulses received in a given time.

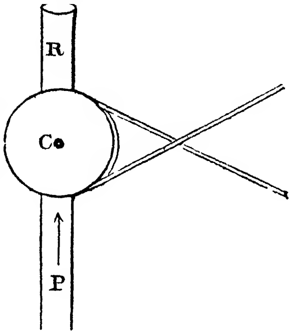


Fig. 50.

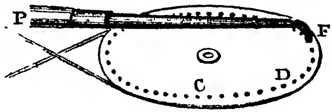


Fig. 51.

In the diagram, Fig. 52, it will be seen that there are eight tubes, *a*, *b*, *c*, *d*, *e*, *f*, *g*, *h*, each exactly fitting over an aperture of the disc, CD; if the disc be now made to revolve there will be puffs issuing at the same moment from *eight* apertures, instead of *one*, as before.

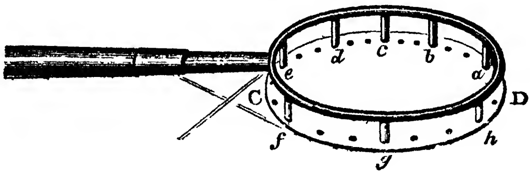


Fig. 52.

But if the disc be now revolving at the same rate as before, it will be found that the sound produced will be the same in *pitch* in both cases, but the *intensity* in the latter case will be vastly greater than in the former. Here we have a confirmation of our previous remark that the *intensity* of

a sound depends not upon the number of vibrations per second which produce it, but upon the amount of energy (measured by the amplitude) expended upon the production of those vibrations. In the above example, the force being eight times more great the intensity of the sound is increased in proportion.

We have now shown that sound may be produced *by periodic movements of a material body*, as a tuning-fork vibrating in air; by a continued succession of oft-repeated *tappings*, as in Savart's Apparatus (see next paragraph); and by a succession of *puffs*; it now becomes necessary to show with more minuteness in what manner the pitch of sounds depends upon the rapidity of the vibrations which produce them.

19. The Relation between the Pitch of a Sound, and the Rapidity of the Vibrations producing it.—*Savart's Apparatus* seems to show this

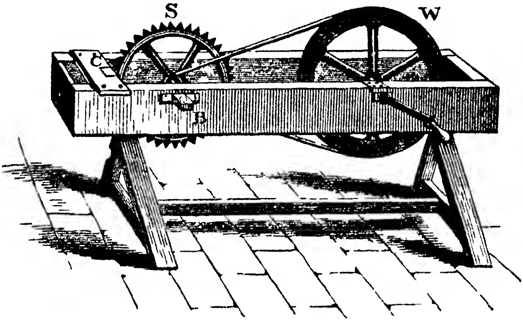


Fig. 58

relationship. As the wheel W revolves it causes the toothed-wheel, S, to revolve also with great rapidity, and this causes a very rapid succession of taps to be given to the piece of cardboard, C, placed in contact with the teeth of S.

By gradually quickening the speed with which W revolves, we gradually increase the number of taps per second received by the cardboard, till these become at last too rapid to be distinguished by the ear as separate taps, but blend together as a distinct musical note, and this note, at first low, gradually increases in pitch till at last (if the rapidity of the revolving wheel still continue to increase) it may even become inaudible once more, because of its having passed the highest limit of hearing of which the ear of the person present is capable.

If we require to find by this instrument the number of vibrations necessary to produce any given note, we must cause this particular note to

be sounded, and then cause the wheel W to revolve with a velocity which gradually increases until the apparatus produces the same note as the one whose requisite number of vibrations we want to know. By means of clockwork attached to Savart's Apparatus (B, Fig. 53) it is possible to find how many times per second the wheel S is revolving at any moment, and by multiplying this number by the number of teeth in S, we find how many taps are given per second to C in order to produce any given note, and as each tap produces a vibration of the air surrounding C, it follows that we find by this means the number of vibrations of the air per second necessary to produce the given note.

This apparatus clearly shows us that *the pitch of a musical sound rises as the rapidity of the vibrations producing it increases.* We may here remind the student, that it has been already shown that *the intensity of a musical sound increases as the amplitude of the vibrations producing it increases.* The pitch of a musical sound is therefore something very distinct from its intensity.

CHAPTER III.

RECTILINEAR MOTION, AND ITS MODIFICATIONS IN THE PHENOMENA OF SOUND, LIGHT, AND HEAT.

20. Rectilinear Motion.—A ball, or any other material body, when set in motion in any direction, will continue to move in that direction until it is either wholly or partially prevented from so doing by the action upon it of some new and opposing force. This, which is true of *matter* in every condition, is also true of *force;* an aerial wave, a water wave, and a wave passing through a solid, whether they be waves of sound, of light, or of heat, will one and all continue to propagate themselves from their centres of disturbance in straight lines until some obstacle presents itself. Neither does the analogy between the transference of matter and the propagation of motion, or force, end here, for just as a ball rebounds from a wall against which it has been hurled, so does the motion which constitutes a wave rebound when it is opposed by a proper obstacle; the laws which govern the recoil in the case of matter govern also the reflection (*i.e.*, the throwing back) in the case of motion.

These laws we must now prepare to state:—

When a wave passing through a medium of a certain density comes in contact with a new medium of a different density, one of two things happens to it; it may either pass into and be propagated through the new medium, or, it may be totally cast back again into its former medium. Whether the first or the second of these phenomena takes place depends upon the difference in the density of the two media, and also upon the angle with which the wave passing through the first medium impinges upon the second.

We may illustrate the phenomena thus: if a boy take a stone and drop it perpendicularly, or nearly perpendicularly, upon the surface of a pond, the stone will certainly sink in the water, but if, instead of dropping it perpendicularly, the boy threw it in a more nearly horizontal direction against the surface of the water, it is well known that the stone would rebound into the atmosphere again; in common language, it would simply "skim the surface" of the water; this is well known to boys as an amusement called making "Ducks and Drakes."

Waves of sound, of light, and of heat, are all liable to this rebounding,

or *reflection*, as it is called; they all also are liable to undergo changes of direction when they enter a new medium, such change of direction being called *refraction*. We will first consider the phenomena of reflection.

21. Reflection.—Let AB represent any reflecting surface, and let a wave starting from O strike A B at right angles to its surface; then this wave would return again to O by the same course with which it proceeded from O. This line, O P, is called the *normal* to A B.

Let now a wave leave M and strike A B at P, as represented in the figure; the wave, in this case, would, after reflection, take the direction P N, according to *the rule that the angle M P O, called "the angle of incidence," is always equal to the angle N P O, called "the angle of reflection."*

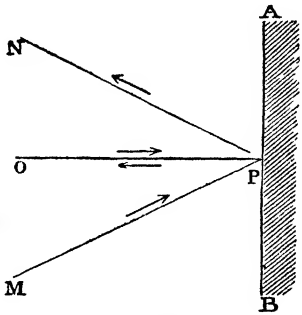


Fig. 54.

If the positions be now reversed, so that the wave should start from N in the direction N P, then it would, after reflection, take the course P M, and the angle N P O would then be the angle of incidence, and M P O the angle of reflection.

There is one other rule of reflection, viz., that the angle of incidence and the angle of reflection are always in the same plane.

Let us now apply these rules to the consideration of

(1.) *The Reflection of Sound Waves by Plane Mirrors.*—*Echoes* are due to the reflection of sound from some large unyielding body, such as a rock, the edge of a forest, or a large building; clouds also frequently reflect sound; the rolling of thunder may be explained as the effect of a series of reflections of the sound caused by an electric discharge between two clouds. The lightning itself is the flash which accompanies the discharge of electricity; the first sound of the thunder is the effect of the atmospheric disturbance caused by that discharge, and the succeeding thunder-rolls are caused by the reflection of this first sound from the many clouds in its neighbourhood.

It is usually assumed that a person can utter *five* distinct syllables per second, so that unless a reflecting body be so far distant from a speaker that a sound occupies at least a fifth of a second in travelling thereto and back, it is clear that the first syllable uttered by the speaker will return before the second starts, or, more exactly, the first part of the first syllable will return and mingle with its latter part. In this case the echo will not be observable.

Now, taking the velocity of sound at 1100 feet per second, it is clear that if a person, A, be 110 feet from a wall, B, the sound proceeding from A will occupy just one-fifth of a second in proceeding to B and back; consequently there will be just time for the echo of one syllable; also, that if the distance A B be doubled, *i.e.*, if A B and back be 440 feet, there will be time for the echo of two syllables; in other words, if a person shout a word of two syllables he will hear them both repeated

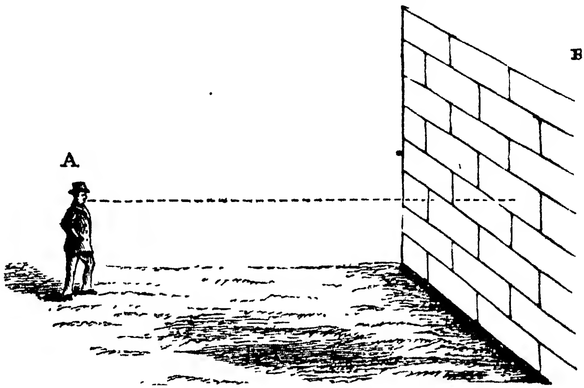


Fig. 55.

after him, but if he shout a word of three syllables he will only hear the last two of them. But if A B and back be 660 feet, *i.e.*, three times what it was in the first instance, then the whole of a word of these syllables would be heard, &c., &c.

Again, if a person stand in the mouth of a large drain and shout down it, the sound may be clearly heard at a great distance in the drain. In

Fig. 56.

this case the sound undergoes reflection from side to side of the pipe, and being thus prevented from extending itself through the atmosphere (see § 15, Fig. 45) it suffers little diminution of intensity, though propagated to great distances through such a pipe. (See Fig. 56.)

On the same principle are constructed the tubes by which verbal messages are conveyed from one part of large public buildings to another. These tubes are fitted at each end with a removable plug which acts as

a whistle. When a person in one compartment of a building fitted with these tubes wishes to convey a message to a person in another compartment, he removes the plug from the tube which communicates with that particular compartment, and blows through it. This causes the whistle at the other end to sound, the person in the room hears it, comes to the tube and receives the message which the other person now speaks through the tube, and this being done both whistles are replaced till the instrument is again resorted to.

The Ear-Trumpet also is constructed on the same principle. Though many different forms of it are made, each of them somewhat resembles a funnel, the wider part being constructed to collect the sound waves, which are then by reflection gathered together and poured through the narrower part into the ear of the person using the instrument.

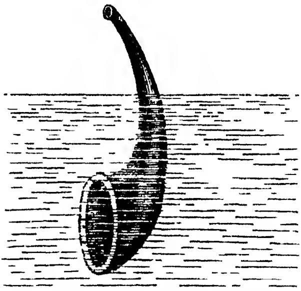


Fig 57 —Ear-Trumpet, as used to determine the velocity of sound in water.

When a person holds his hand to his ear to enable him to catch a sound the better, he is simply using his hand as a funnel for collecting sound waves.

The Speaking-Trumpet is used for enabling a person to make his voice heard at a great distance. The mouth of the speaker is applied at A (Fig. 58), and the sound wave having been reflected from side to side of

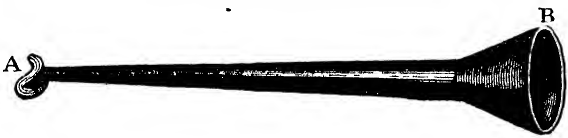


Fig. 58. —Speaking-Trumpet.

the tube A B, issues at B in such a form as leads to its being propelled a greater distance, without loss of intensity, than would be the case if the person spoke without the trumpet.

When a person holds his hands to his mouth to enable him to make his voice heard at a greater distance, he really uses them as an imperfect sort of speaking-trumpet.

A further Illustration of the Reflection of Sound is the following:—

Take a watch which ticks pretty loudly, and holding it about three inches from your ear listen to its ticking for a few moments till the loudness of the ticks is well appreciated by your ear. Then, keeping your head and the watch in the same positions, take a large piece of card-board in your other hand and gradually bring it up behind the watch, so that the watch is between your ear and the card-board; the tickings will gradually become louder as the cardboard nears the watch, an effect evidently due to the reflection of sound waves by the cardboard, in consequence of which the ear receives not only the waves of sound which proceed directly from the watch, but also others which, started in other directions, but meeting with the cardboard, are by it reflected back into the ear. (See Fig. 59.)

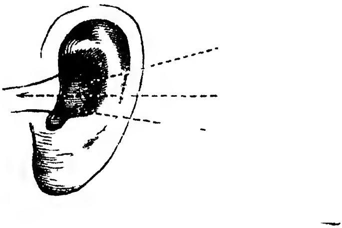


Fig. 59.

(2.) **Reflection of Light Waves by Plane Mirrors.**—It has been already mentioned that *light travels always in a straight line* until its course is changed by the interposition of some obstacle. An interesting experimental proof of this is the following:—

In the accompanying figure the light from the smaller gas-jet, A, is caught upon a screen at A^1 after passing through a hole in the card-board

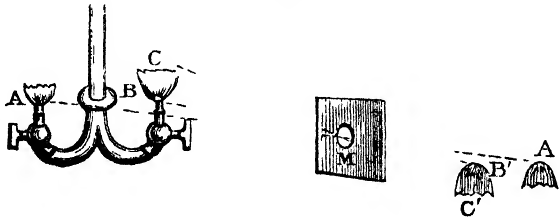


Fig. 60.

at M; the light also from the larger gas-jet, B C, is similarly caught upon the screen at B^1 C^1. An inspection of the figure shows that the jet A, which is on the left hand in the chandelier, is on the right hand on the screen, and that the position of the jet B C is also therefore

inverted from right to left. Further, it is also clear that the images of the jets A and B C are "upside down," as it were, on the screen for a similar reason.

When a sunbeam breaks through an aperture into a darkened room its course is seen to be perfectly straight. To observe this well the atmosphere of the room should be rather dusty, for *light is not itself visible*, and therefore the course of a ray of light through the atmosphere can only be traced by its illuminating effect upon the dust and other particles in its path.

Shadows are due to the tendency of light waves to travel always in a straight line, for when a wave of light comes into contact with an opaque body (*i.e.*, a body through which it cannot make its way) it cannot bend its course round into the space immediately beyond that body,* and the space thus deprived of light is called a *shadow*.

The extent and the shape of a shadow depends upon whether the light proceeds from a single luminous point or from a luminous body of known dimensions.

Fig. 61 shows the kind of shadow cast by the sphere C when the light proceeds from a single luminous point, P.

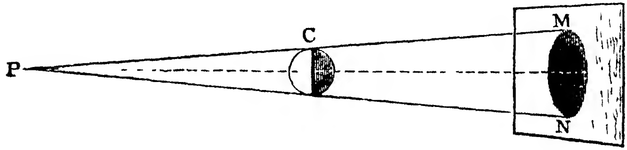


Fig. 61

If the plane surface P M N be imagined to revolve upon the line P O which passes through the centre of the sphere C, this revolving surface will describe a cone of space which will include,—and whose outer edge will always be in contact with,—the sphere C. It is clear now that the apex of the cone, as far as C, will be a cone of light, and that the remainder of the cone—in other words, that part of the cone which is on the side of C remote from P—will be a region of darkness. If, therefore, a screen be introduced as shown in the figure, a shadow, M N, will be cast upon it.

Let us now consider the case in which the light proceeds from a luminous body of known dimensions, such as S in Fig. 62.

Of all the rays of light which leave the luminous body, S, it is evident from the figure that none can enter that part of the cone, P A B, which lies between the sphere C and the screen on which the shadow is cast.

* Not absolutely true, but sufficiently so for our present purpose.

Again, it is evident that of the rays proceeding from *a*, all those whose course lies in the cone *a* A A′ will be intercepted by C; therefore of this cone that part which lies between C and the screen will be a shadow; consequently, an observer situated anywhere between A′ and B will be unable to see an object at *a*, though he could see one at *b*.

Again, in the same way, that part of the cone, *b* B B′, which lies between C and the screen, is also a shadow, so that an observer stationed anywhere between B′ and A will be unable to see an object at *b*, though he could see one at *a*.

Concerning the whole cone, P B A, it is therefore clear that that part of it which lies between C and the screen is a total shadow, so far as any light proceeding from the luminous body S is concerned, but that such portions of the cone P′ B′ A′, as lie between C and the screen, but are not

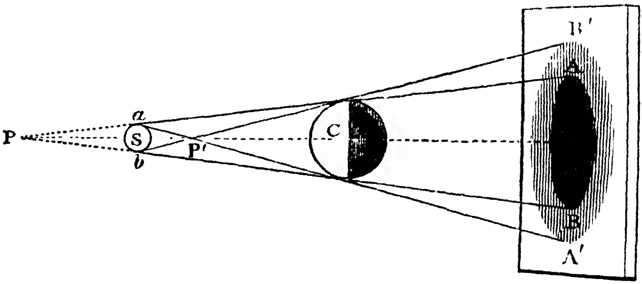


Fig. 62.

included in the cone P B A, are only in a partial shadow so far as the light proceeding from S is concerned, that is, they are deprived of *some* of the light rays proceeding to them from S, but not *all*.

In this way we get an appearance produced on the screen such as is shown in the figure, viz., an inner circle of total shadow, called the *umbra*, and an outer ring of partial shadow, called the *penumbra*.

That *light undergoes reflection, according to the Rules stated on page* 63, admits of easy experimental demonstration by means of the apparatus shown in Fig. 63.

Two telescopes, *t* and *t*′, move round a vertical circle whose circumference is graduated as shown in the figure. The insides of these telescopes are blackened. At the centre of the circle is the mirror, M, fixed horizontally.

A lighted candle having been placed opposite the eye of the telescope *t*′, some of the rays of its light pass through it, and being reflected from M proceed towards the telescope *t*, as shown in the figure. If

the telescope t be anywhere on the circle except in that position in which the angle O M t is equal to O M t', the person looking through t will see nothing of the candle-light passing through t'; in other words, in order to catch the rays of light passing through t', the observer looking through t must place it so that the degrees O t may equal the degrees O t'.

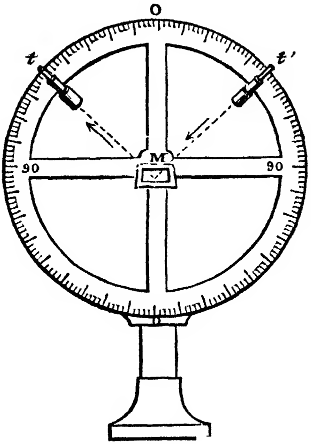


Fig. 63.

It is thus proved that *the angle of incidence is equal to the angle of reflection.* (§ 21, p. 63.)

Again, if the telescopes, t and t', be in the positions required by the law just repeated, but at the same time the left half of the vertical circle on which they move be bent back, so that *the left half of the circle is not in the same plane as the right,* then the observer looking through t will find it impossible to catch the rays passing through t' and reflected from M, for, *by the second law of reflection, the incident and the reflected ray are always in the same plane,* therefore a person looking through a telescope moving in one plane can never catch rays of light travelling in another plane.

Before we proceed further in our study of light, it will be necessary to explain the following terms :—

(1.) *A Mirror* is a hard-polished surface, usually either of glass or metal, which serves to reflect light. The surface of a sheet of still water, of mercury, or of any other substance whose surface reflects light, may also be regarded as a mirror.

(2.) *An Image* is the place at which an object appears to be present.

In the accompanying figure let A be a luminous point; then from A rays of light will proceed in all directions, as indicated by the arrows; of these let one enter the eye of an observer at B; this observer will see A in its actual position. Now let other rays fall upon the mirror and be reflected from it as shown by the thick lines in the figure, each ray so reflected making its angle of incidence, i, equal to its angle of reflection, r, and let one of the reflected rays also enter the eye of the observer at B. Then this observer will see an image of A at A′; he will thus see two images of A, one due to a *direct* ray and one to a *reflected* ray. A similar thing would happen to another observer at C.

In this case, and the same applies to every case of reflection of light from plane mirrors, the reflected rays *appear* to diverge from a point A′ situated as far behind the mirror as the point A, from which they *actually* diverge, is before the mirror.

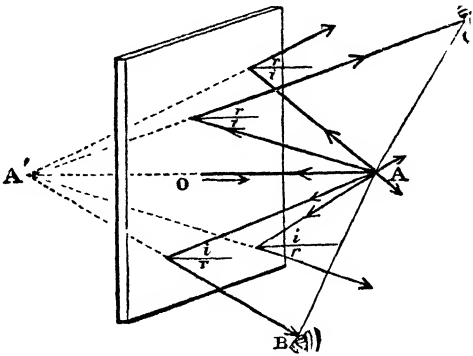


Fig 64.

It will be noticed that the ray A O, which makes a perpendicular with the surface of the mirror, returns from it to A by the same course it pursued to reach the mirror; hence the rule that *a ray of light which reaches a mirror, by a course which coincides with the normal at its point of incidence, will be reflected from the mirror along the same normal.*

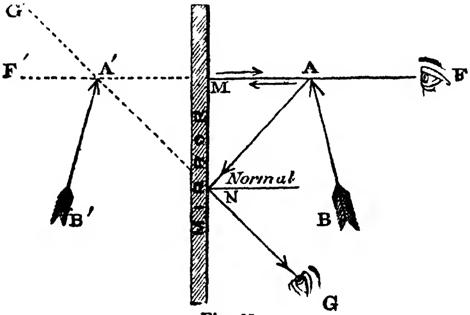


Fig. 65.

In Fig. 65 the ray A M falls perpendicularly upon the mirror, and is therefore reflected back again along its incident course, consequently an observer at F will receive the ray M A as though it originated at some

point along the line F′F. Similarly, an observer at G will receive the ray N G as though it originated at some point along the line G′ G. But the point A′ is the only point common to the two lines, F′ F and G′ G; therefore, *if the observer at F and the one at G both see the same image* of A, that image must be seen as being at A′.

But it may perhaps be doubted whether they do see the same image; let us therefore endeavour to prove that they *must* necessarily do so.

From the accompanying figure it is evident that the two rays A M, A N, both enter the eye at F after reflection; it is further evident that these rays after reflection enter the eye at F as though they came originally from A′; therefore an image of A is seen at A′ by an observer at F. But again, it is evident that the three reflected rays which enter the eye at G also appear to come from A′, so that an observer at G would see the image of A at A′ just as did the observer at F; and in the same way it can be shown that to every observer who sees an image of A in this mirror the position of that image will appear to be the same, and that position is as far *behind* the mirror as the point itself is actually *before* the mirror; and the same remark applies to every other point of the object A B, consequently the image of the whole object, A B, will be seen behind the mirror equal in size and similar in shape to the object itself, and situated as far behind the mirror as the object itself is before the mirror.

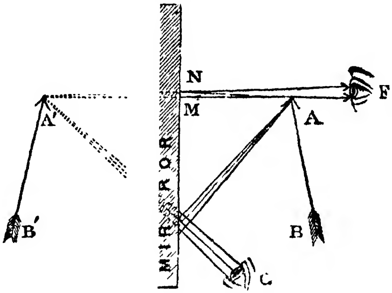


Fig. 66.

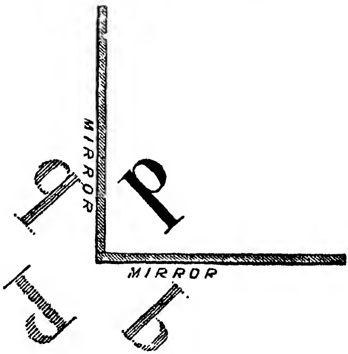


Fig. 67.

A curious effect of the reflection of light by plane mirrors is shown in the accompanying figure, in which are represented two plane mirrors placed at right angles to each

other. It will be noticed that the images formed by the reflected rays are all lateral inversions of the object P placed before the mirrors.

This lateral inversion always accompanies the formation of an image by a plane mirror, and some further curious effects are obtained in consequence; one of them being the following:—

In Fig. 68 let A be a shepherd holding his crook in his left hand and a flower in his right. Then, from every part of his person rays of light disperse themselves in all directions, and among these will be one ray C C′ proceeding from C to C′, and another proceeding from F to F′, and these rays, leaving C′ and F′ as reflected rays and entering the eye of an observer at E, will impress that observer with the idea that the figure B is that of a shepherd holding his crook in his *right* hand (not his *left*, as in A), and a flower in his *left* (not his *right*, as in A); in short, the whole image B is a lateral inversion of the object A.

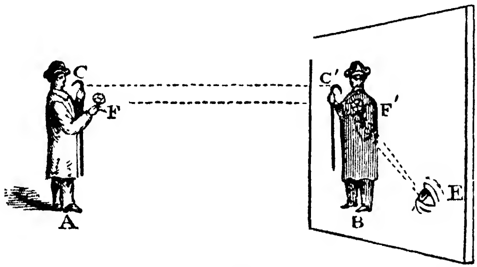


Fig. 68.

In Fig. 67 it will be observed that, counting the object itself as one, there are *four* images of the same object presented to the eye; if, however, the mirrors had been inclined to each other at an angle of 60°, the number of images, including the object itself, would have been *six*, according to the rule that

$$\textit{the number of images} \text{ (including the object itself)} = \frac{360^\circ}{\textit{the number of degrees at which the angles are inclined to each other.}}$$

If, therefore, the two mirrors be held parallel to each other, the denominator of this fraction being O, the number of images will be unlimited, according to the formula that

$$\frac{360^\circ}{0^\circ} = \frac{360}{0} = \text{Infinity.}$$

This may be best shown by placing a lighted taper between two looking-glasses, both placed perpendicularly, as shown in Fig. 69. An image of the taper will be formed on each of the mirrors A and B, and an image

of the image on A will be formed on B, and an image of the image on B will be formed on A, &c , &c., &c. Thus an unending succession of images is to be seen by a person looking either at A or at B.

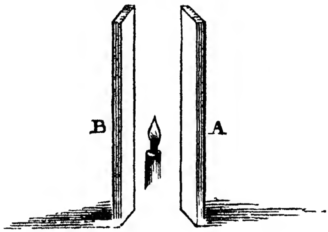


Fig. 69.

The Kaleidoscope is a toy the principle of which is the multiplication of images by two mirrors set at an angle to each other. It consists of a tube of metal or cardboard which contains either two long pieces of smoked glass, or two pieces of silvered glass set at an angle with each other. The tube is closed at one end by a covering in which is a hole for the person using it to look through; at the other end are various objects, such as bits of coloured glass, beads, &c. The long pieces of glass act as mirrors, and the consequence is, that when the instrument is turned round in a person's hands the small objects at the end continually change their positions, and thus give rise to an endless variety of appearances, some of which are extremely pretty.

These effects may be magnified and diversified by using three reflecting plates instead of two; these are arranged in the tube so as to form the three sides of a triangle, and as each pair of reflectors serves to form a kaleidoscopic pattern, it follows that the whole three of them together produce pretty much the same effect as a combination of three kaleidoscopes.

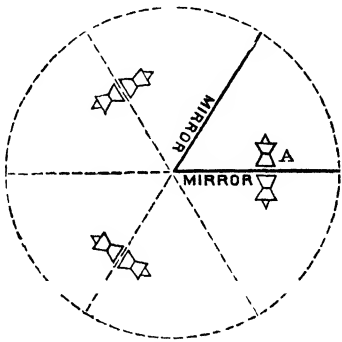


Fig 70.

Fig. 70 represents the images in a kaleidoscope formed by two mirrors and three small bits of glass which have fallen together symmetrically to form the object A.

Another somewhat similar effect is produced by holding a lighted candle close to a common looking-glass. Such a glass consists of a piece of plate-glass silvered at the back. When a ray of light, A B, falls upon such a mirror, part of it is at once reflected, as at B C, while the remainder enters the glass and (with a somewhat changed course) propagates itself

through the glass towards the silvered surface, D G L, at the back of the mirror. Here it again undergoes reflection towards the front surface of the *glass*, and, reaching E, part of the light there undergoes reflection towards G, while the other part enters the air as E F. That part which was reflected towards G is again reflected from G towards J, and at J the same happens to it which happened at E, *i.e.*, a portion of it is reflected towards L, while another portion enters the air as J K.

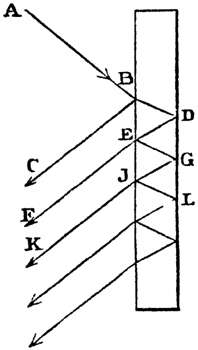


Fig. 71.

In Fig. 71 the ray A B is represented as falling rather obliquely upon the mirror; a little consideration will show us, however, that the more perpendicularly the ray A B strikes the mirror, the less will be the distance separating the rays B C, E F, J K; it thus may happen that these rays may be so close together that the eye of an observer fails to distinguish them as separate rays proceeding from different points; this is the case when the eye of the observer is placed directly, or nearly directly, behind the candle, with regard to the mirror. If, however, the candle be placed *close* to the mirror, and the eye of the observer be also placed close to the mirror but at a distance from the candle, and the observer then look towards that part of the mirror which is close to the candle, he will observe a number of images of the one candle arranged as in Fig. 72.

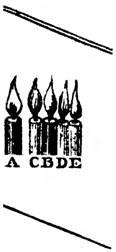


Fig. 72.

Each of these images is the effect of the splitting up (by reflection) of such a ray as A B (Fig. 71) falling obliquely upon the mirror.

In this figure (Fig. 72) A is the candle itself; B the brightest image of it; and C, D, E are fainter images.

It has been already stated that the image of an object appears as far *behind* a mirror as the object itself is *before* the mirror. If now M be a plane mirror (Fig. 73) and A an object placed before it at a distance of 5 feet, the image of A will appear to be at A′. But if A keep its position while M is moved *one* foot nearer A, it is evident that A′ must come *two* feet nearer A (Fig. 74). Similarly, if M be caused to move one foot away from A, the image A′ will thereby be caused to move off two feet farther from A.

Fig. 73.

Fig. 74.

And it is evident that since the image travels in these cases over twice the space performed by the mirror, the velocity of the image is double

that of the mirror; it is thus found that *when a mirror changes its position in a direction perpendicular to its own planes, the image of an object placed before it advances when the mirror advances and recedes when it recedes, and that this advancing or receding motion of the image is always performed with a velocity which is double that of the mirror.*

In the same way we find that when a revolving mirror reflects light from a stationary object, the number of degrees by which the angle of reflection increases is equal to double the number of degrees through which the mirror passes, or, in other words, *the angular velocity of the reflected ray is double that of the mirror which reflects it.*

In Fig. 75 it can be seen that when the mirror—which revolves on O—is in the position A B, the angles of incidence and reflection are each angles of 30°; but when the mirror has travelled through 15° to gain the position A′ B′, the reflected ray has been caused to take up a new position

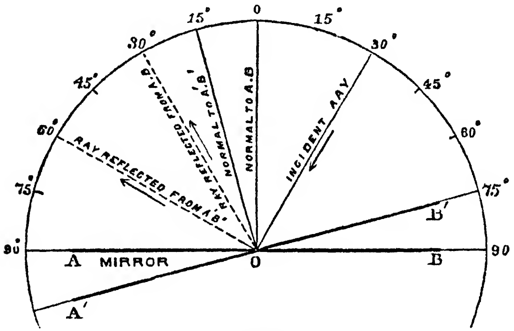


Fig. 75.

removed by 30° from its former position. While, therefore, the mirror has moved through 15°, the reflected ray has moved through 30°; therefore *the angular velocity of the reflected ray is in this case double that of the mirror which reflects it,* and a little consideration will show us that this must be so in all such cases.

(3.) **Modes in which Heat is Propagated from Point to Point; Reflection of Radiant Heat by Plane Surfaces.**

There are three ways in which heat may be translated from one point to another, viz.

1st. **Convection,** which is the actual *carrying* (or *conveying,* hence the word "*convection*") of heat from one place to another by a body *which itself moves* and carries the heat with it, as when a body of heated air rises into the higher parts of the atmosphere.

2d. **Conduction**, which is the passing on of heat rays from particle to particle of a stationary body; as when a poker—one end of which is in the fire—becomes heated at its other end which is some distance from the fire. In this case the poker as a whole remains without motion, but the heat of the fire passing from one end of it to the other does so by reason of a vibratory motion communicated by the fire to the particles of the poker in immediate proximity with it, and by these transmitted to others near them, and so on to the other end of the poker; thus the poker as a whole remains unmoved, while each of its component particles is in a state of more or less rapid vibration.

3d. **Radiation**, which is the passing of heat from point to point of space by means of vibrations communicated to the ether which is supposed to permeate all bodies, and to fill all space not occupied by ponderable matter; as when the heat of the sun reaches the earth and other heavenly bodies, and does so by *passing between* the particles of which our atmosphere is composed, but heating none of them. Such heat travels always in straight lines, or rays, and is hence called *radiant heat.*

We will now describe some experiments illustrative of these different methods of transmitting heat from point to point of space.

Water, like most other bodies, expands when heated and contracts when cooled, so that, bulk for bulk, it is rendered lighter by heating it and heavier by cooling it; consequently in Fig. 76 the water just above the mouth of the Bunsen's burner, B, becomes lighter than that surrounding it. It consequently rises towards the top of the water while cooler water comes in to take its place, and this becoming hot in its turn also rises, and thus is established the circulation shown in the figure. In Fig. 77, on the contrary, a circulation, due to the presence of a lump of ice at the surface of the water, in all respects the reverse of that in Fig. 76, is set up and maintained.

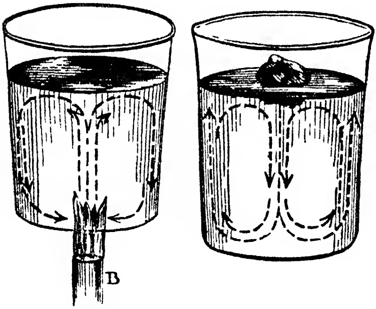


Fig 76. Fig. 77.

In both these cases heat is *carried* from place to place by the moving water; that water which rises carries with it more heat than that which sinks, and *vice versâ,* that which sinks carries with it less heat than that

which rises; in both cases, however, *heat is actually carried* by moving matter.

These experiments illustrate the transmission of heat by *convection*, and it is here particularly to be noted that a cold body can as well give rise to convection currents as can a hot body. And it may also here be noted that there is really no such thing as cold; "*coldness*" is simply *absence of heat*, and it is thus clear that convection currents will always be set up whenever one portion of a fluid body—be it either liquid or gaseous—possesses more heat or less heat than other portions beneath it or surrounding it. If, however, the hotter portion be superincumbent upon the colder, such currents are *not* set up, and as the following easy experiment will serve to show.

Fig. 78 represents a test-tube filled as full as possible with water, and having a piece of ice at the bottom. As ice is lighter than water it would rise to the surface unless prevented; this can be accomplished by twisting a piece of copper wire round the ice; it then sinks as shown in the figure.

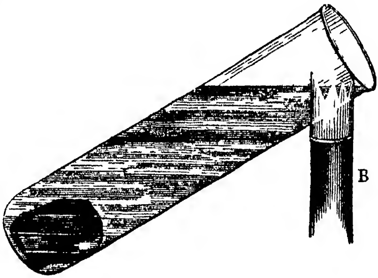


Fig 78.

The water at the surface is now heated by means of the Bunsen's burner, B, and it can then be seen that the ice remains a good while unmelted, because the heated water at the surface has no tendency to descend to the bottom of the tube where the ice is. Ultimately, however, the ice will be melted because the heat at the surface will travel downwards *by conduction*, the reason why it is so long in doing so is that water, like most other fluids, does not possess the power of conveying heat rapidly from particle to particle of its own substance, in other words, *water is a bad conductor of heat.*

To make the above experiment perfectly conclusive, put another piece of ice in a similar tube, and let it float at the surface of the water, and place the burner, B, at the bottom of the tube, thus to obtain convection currents, and then notice how rapidly the ice will melt.

From this experiment, it is clear that when rooms are heated by a hot-water apparatus the furnace for heating the water must be lower than the rooms to be heated, for hot water cannot be made to descend to a lower level. The same remark applies to air and other gases. These have very small *conducting* powers indeed; hence rooms can be kept cool in summer and warm in winter by making their windows double, so as to

include a quantity of air between the inner and the outer panes of glass. The air so enclosed prevents the passage of heat by conduction outwards in winter and inwards in summer.

In the same way woollen clothing is warmest in winter and coolest in summer, because its heat-conducting power is smaller than that of most other substances used for clothing. In winter, therefore, it refuses, as it were, to do much in the way of conducting off animal heat from the body, and in summer it declines to do much in the way of conducting solar heat inwards to the body. For the same reason we wrap ice in flannel to keep it from melting in hot weather. It must be carefully noted that *substances used for clothing possess no heating powers of their own;* they act simply by preserving to the body the heat generated in itself. Black substances, as a rule, possess higher radiating powers than do white ones. Consequently, a black garment serves quicker to cool one—by allowing heat to be abstracted from the body—than a white garment. But *substances which are good radiators of heat, that is, which possess great powers of parting with heat, are also great absorbers of heat*, and *vice versâ*, being thus not unlike one to whom a great fortune comes suddenly and unexpectedly, and who at once begins to squander it, according to the adage "*Lightly come, lightly go.*" Therefore, dark substances, which radiate heat freely, also absorb it freely; consequently a black coat is not only cooler in winter than a white one *of the same material*, but is also warmer in summer.

Polished substances absorb heat less freely than do rough unpolished ones; hence, in order that a kettle may absorb heat quickly and thus boil in a short time, it is well that it should be *black* with soot, but in order that it may keep hot a long time after being removed from the fire, it is necessary that it should be polished and *not* black, for the polished surface, being a poor absorber of heat, is also a poor radiator. Hence it would happen that, if a brightly polished teapot were filled with hot water, it would cool slowly, because of the low radiating power of its polished surface; but if it be now surrounded closely with a rough flannel, it would cool quicker, because of the higher radiating power of the flannel over the polished surface of the teapot. But the student will ask, "*Why do we, then, use 'cosies' for keeping teapots warm?*" The answer is that a cosy does not fit *closely* to the teapot, but is always made to fit so loosely that it encloses a considerable volume of air between itself and the teapot: this air, being a bad conductor of heat, acts as a check upon the passage of the heat from the teapot to the cosy itself and so to the outer air. Radiant heat is subject to reflection, like light, and the cosy again serves to restrain the passage of heat from the teapot by reflecting it back again after its passage through the enclosed air.

The radiating power of a body has thus been shown to agree with its absorbing power; in other words, we have pointed out the *reciprocity of*

radiation and absorption. Further, we have shown that the radiating power of a body depends upon

1st, *The roughness or smoothness of its surface;*

2d, *The colour of its surface.*

It also depends upon

3d, *The material of which its surface is composed.* This is clear from the fact that the cooling of a body may be accelerated, in certain cases, by surrounding it with flannel as mentioned above.

The cooling (or heating, as the case may be) of vessels may be retarded by surrounding them with any loosely-compacted substance, such as straw, sawdust, felt. The action of these substances, in preventing the transmission of heat, is supposed to be due to the presence of air in the interstices of the substances. For this reason felt is much used for covering outhouses, and sawdust and straw in packing ice.

Sound, as well as heat, has its transmission retarded by sawdust and such substances. For this reason the under parts of railway carriages are sometimes lined with layers of sawdust, and the sound of the wheels is thereby much diminished. As heat and sound, in this case, are obedient to the same law, it is but fair to argue that they are of similar natures, and that therefore the conduction of heat is a phenomenon exactly resembling the transmission of sound, both consisting in the propagation of a vibratory motion from particle to particle of a material body.

As already stated, *gases and liquids are poor conductors of heat,* so also are all organic substances: *the best conductors are the metals;* of these silver stands first: thus, if the conducting power of silver be 100, we may state those of some other metals thus—

Silver 100	Gold 53	Iron 12	Platinum 8
Copper 74	Tin 15	Lead 9	Bismuth 2

The different relative conductivities of metals may be illustrated by experiments, thus—

A B, A C, are bars of iron and copper respectively, each of the same size, and each having small balls of wood attached to it at equal distances

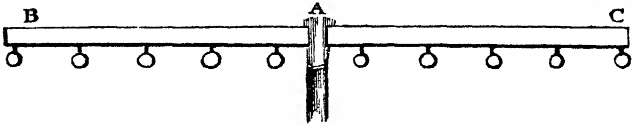


Fig. 79.

by means of wax. A Bunsen's burner at A serves as a source of heat to both bars, and the greater conductivity of the copper is shown by the greater number of balls which fall from A C in a given time, owing to the melting of the wax which attached them to the bars.

Fig. 80 shows an apparatus constructed to act on the same principle as the last: *a*, *b*, *c*, *d*, *e*, are rods of iron, copper, wood, glass, &c., coated with wax and inserted in the side of a trough, which is then filled with boiling oil or water. The heat is found to be conducted at different rates through the rods, *a*, *b*, *c*, *d*, *e*, as is seen by the different distances from the trough to which the wax on them melts.

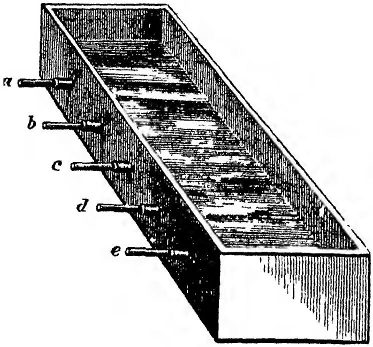


Fig. 80.

Another method, proceeding on a somewhat different principle, is the following:—

In Fig. 81 is represented a bar of metal, heated by a Bunsen's burner at one end, and having holes drilled in it at regular distances, into which the tiny thermometers, *a*, *b*, *c*, *d*, *e*, *f*, *g*, are inserted.

As the heating continues the mercury gradually rises in these thermometers, but at last becomes stationary in them all, and when this point is reached it is found that the heights of the mercury in these thermometers gradually become less towards the end farthest from the heat.

The amount of the falling off of the heat for this bar having been noted, the bar is removed, and a similar one of a different metal is substituted, and the falling off in this case is also noted. Suppose it to be less in this case than in the other, is the second metal a better or a worse conductor of heat than the other?

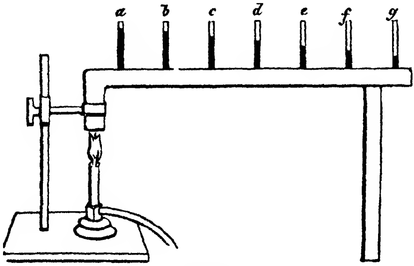


Fig. 81.

Before we can answer this question, we must know why the mercury becomes stationary in these thermometers. Now, we know that the only possible reason for this is that its temperature ceases to rise, in other words, it ceases to receive more heat than it loses by radiation into the surrounding atmosphere. The reason why the mercury becomes station-

ary then is, that the bar has now entered upon that state in which it loses as much by radiation into the air as it gains by conduction from the end near the burner. But from the time the heat started on its course towards a, it has been constantly decreasing in amount, because of the radiation going on; also, while passing from a to b, radiation has also been continuing, and is clear that the longer it takes the heat to pass from a to b the greater will be the loss by radiation which takes place, and the greater therefore will be the difference between the heights of the mercury at a and b. Consequently if, as we supposed, this difference in the case of the second bar is less than that in the first bar, the second bar is of the two the better conductor.

Fig 82.

The conductivity of silver being 100, that of German silver is 6; therefore, if two spoons, one of silver and the other of German silver, be placed on a tripod in a beaker of hot water (Fig. 82), the heat will reach a bit of phosphorus, P, on the silver spoon, and inflame it long before the same thing happens to the phosphorus on the other spoon.

An instance of *the reflection of radiant heat by plane surfaces* is that which takes place when the heat from a fire is reflected forwards into the room by means of glazed tiles round the fireplace.

4. *Reflection of Sound, Light, and Heat by Curved Surfaces.*

(1.) When the light from a body is reflected by a surface which is not flat, it almost always produces a distorted image of the object. In every case in which the image of the object is *not* so distorted, the mirror, if not a plane one, is one whose surface forms a section of a sphere. Such spherical mirrors may be either *concave* or *convex*.

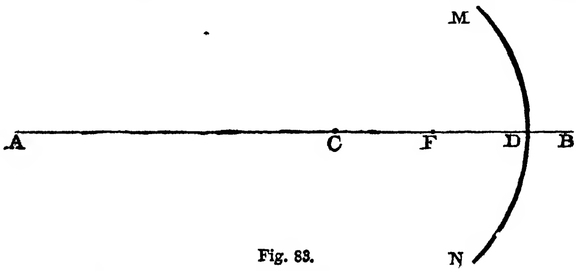


Fig. 83.

If in the straight line AB (Fig. 83), we take the point C as the centre of the arc MN, then MN represents *a spherical mirror*, concave to light coming to it from the left: the line AB represents its *principal axis;* the point C is its *centre of curvature;* and the point D is *the middle of the mirror;* and the point F, situate midway between C and D, is *the principal focus.* The distance FD is *the focal length* of the mirror.

(2.) Geometrically, *a sphere is considered to be made up of an infinite number of minute flat surfaces*, and we make the same supposition in considering the reflection of light from curved surfaces. In order, therefore, to understand the reflection of any particular ray of light from the curved mirror MN, we consider only what would happen to it if the surface of MN at the point of incidence of that particular ray were *flat* instead of *curved.* Now we know already (page 69) that, in the case of a ray of light incident upon a plane mirror, the angle of incidence is equal to the angle of reflection; but, in order to apply this to the case of curved mirrors, it becomes necessary to know how *to find the normal to a curved surface.* By geometry we know that a line which just touches a circle, as ABC (Fig. 84), is necessarily at right angles to a radius, BO, of the circle, drawn to the point of contact. If then we regard the point B as part of the circumference of the circle, it follows that the radius BO is at right angles to the point B.

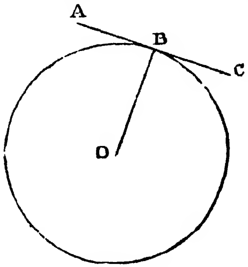


Fig. 84.

From which we learn that *a normal to any point in a spherical mirror,*

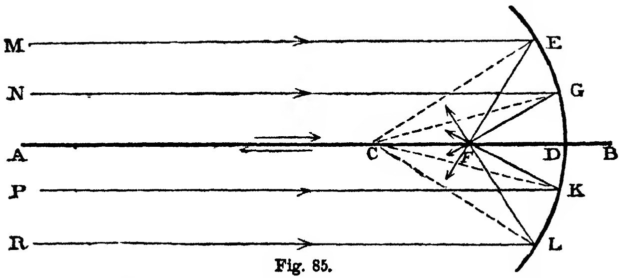


Fig. 85.

may be described by joining that point to the centre of curvature of the mirror.

(3.) In the accompanying figure (Fig. 85), if a ray of light leaving A travel along the principal axis AB, it will again return along it to A once more, for, in this case, CD is part of the incident ray; the angle of

incidence is therefore *nil*, and the angle of reflection is consequently also *nil:* therefore the ray returns by the way it came. Now the rays ME, NG, PK, RL, and all others which, like them, proceed to the mirror in directions which are parallel to AB, will, after reflection, pass through the point F, which, as we have already said, is *the principal focus of the mirror*, and is situated midway between the points C and D.

In the figure the normals are indicated by the dotted lines, and it must carefully be noted that the angles of incidence and reflection are in each case equal to each other.

If a luminous point be placed at F, then it is clear that the rays FE, FG, FK, FL, will, after reflection, take the courses EM, GN, KP, LR, because they thereby conform to the law that the angle of reflection is equal to the angle of incidence.

(4.) In Fig. 86 it is clear that the ray PD will, like AD in the last figure (Fig. 85), return by the way it goes to the mirror. Now we know

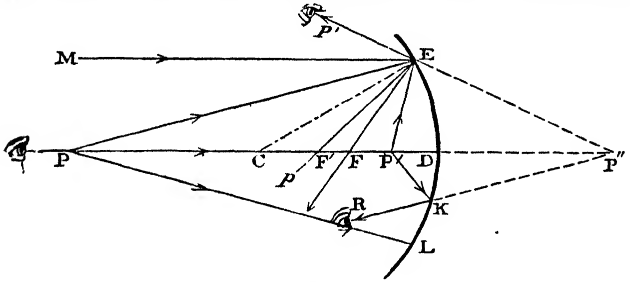


Fig. 86.

that all the rays, PE, PD, PL, which leave the point P, will meet together in some part of their reflected courses; since, therefore, the reflected course of one of them, PD, is known to be DP, it follows that *all those of the rays leaving P which fall upon the mirror must meet together* (*i.e.*, *be focussed*) *at some point in PD.*

But, since the angle of reflection, CEF, corresponds to the angle of incidence, MEC, it is evident that an angle of reflection smaller than CEF will correspond to the incident angle PEC, which is smaller than MEC; therefore the ray PE will, after reflection, take a course somewhere between EC and EF, as Ep. Therefore F′ will be the point at which all the rays from P, which are incident upon the mirror, will be brought to a focus.

And similar reasoning will show us that if the point P be brought nearer to C, then the point F′ will also come nearer to C till they both meet at C; for then the incident ray will take its course by way of the normal CE, and will therefore return by the same way.

But if we still imagine P to move on its course towards the mirror it will presently reach F′, and then the focus will be at P, so that the luminous point and its focus have made an interchange of positions. Because of this interchange—which is always practicable—the two points, P and F′, are called *conjugate foci.*

When P reaches F its rays, of course, leave the mirror in directions parallel with each other and with the principal axis. (See 3, above.) But, when it passes F and so attains a position, P′, where will its rays go after reflection? It is clear that the angle of incidence P′EC is greater than the angle of incidence FEC, therefore the angle of reflection corresponding to P′EC must be greater than the angle of reflection CEM; evidently, then, the ray P′E will, after reflection, take the course E*P′*. But the ray P′D will return, of course, by the way it goes to the mirror, *i.e.*, in the direction DP′. But the courses E*P′* and DP′ will never meet towards the left, *i.e.*, towards the direction in which the reflected rays move; but they will *appear* to come from a point, P″, *behind* the mirror, as shown by the dotted lines. In the same way the ray P′K, after reflection, takes the course KR, as though it also came from P″.

Such a point as P″ is called *a virtual focus*, because, although rays of light do not really proceed from it, they produce upon the eye an effect which is the same as though they did actually proceed therefrom; and the image at P″ is *a virtual image* of the object at P′.

(5.) Having now shown the different positions of the image of a luminous point which is made gradually to approach a concave mirror along the line of its principal axis, we will now endeavour to see what happens when the object is *not* on the line of the principal axis.

But, to prevent the possibility of misunderstanding, we will here remark that the eye of an observer so placed as to receive *one* of the reflected rays in the last figure—or, indeed, in any other case—will see an image of the object. Thus, the observer at P sees the image P″, so do the observers at *P′* and R; although the positions of the observers vary, that of the image remains the same in all three cases.*

Let it now be required to find the point at which all the light rays proceeding from the point P (Fig. 87) will be brought to a focus.

Of the rays proceeding from P in all directions there will be one, PL, which will pass through, C, the centre of the curvature; but this one will strike the mirror at right angles to its surface, and will therefore return along its own course again: therefore, if PL meet any other of the rays proceeding from P, it must meet them somewhere in the PL or PL produced.

And this must evidently be the case whatever be the position of the point P.

---

* Not absolutely true. See page 91.

The line PL is called *a secondary axis*, and it is now clear that whenever we are called upon to determine the position of the image of a luminous point formed by a spherical mirror, the first thing we must do is to join that point with the centre of curvature of the mirror, C (as PC, above), and produce the line to meet the mirror (as PCL, above); the line thus formed is called *the secondary axis* if the point be situated as P in the accompanying figure, and *the principal axis* if it be situated as P′ in this figure, *i.e.*, in the line of a normal drawn at, D, the middle of the mirror.

We have shown that if the rays from P be focussed at all it must be at a point somewhere on the line PL (or PL produced, if necessary). Now, if we can find the point at which any one of the rays leaving P will, after reflection, cut PL, we shall know that all the other rays proceeding from P will cut it at the same point. But we know that the ray PR, parallel to the principal axis, will, after reflection, pass through F as RF, and, continuing in this course, it will cut PL in P″; therefore P″ is the

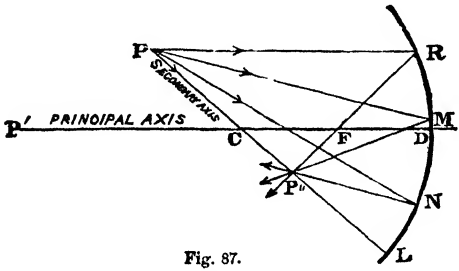


Fig. 87.

focus for all the rays proceeding from P which fall upon this mirror: *e.g.*, the rays, PM, PN, both are reflected to pass through P″.

We have to remember then that, in order to fix the position of the image of a luminous point not situated on the principal axis, we must

1st, Draw its secondary axis; and

2d, Draw one of its rays parallel to the principal axis, reflect it through the principal focus, and continue its course till it intersects its secondary axis.

N.B.—It will be observed that P and P″ are conjugate foci, and therefore rays proceeding from P″ will be focussed at P.

It is now clear that *if the luminous point be farther from the mirror than C, its image will be formed somewhere nearer the mirror than C, but not so near as F, and vice versâ.*

(6.) In Fig. 88 the point P is nearer the mirror than is the point F: in this case we proceed, as before, to draw the secondary axis, PC, and then to trace the course, PMF, of the ray, PM, whose incident course is

parallel to the principal axis; but we find that, in this case, the lines PC and FM can only be made to meet by producing them backwards, as shown by the dotted lines, and in this way we get a virtual image of P at P′.

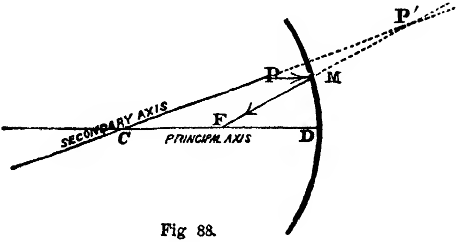


Fig 88.

(7.) Having now considered the positions of the images of a luminous point, let us proceed to apply this knowledge to the consideration of the positions of images of a luminous body of sensible dimensions.

In the present figure (Fig. 89) the points A′ B′ are determined in the same manner as was P″ in Fig. 87. (See 5, above.)

From this figure we see that *if an object be farther from a concave spherical mirror than is its centre of curvature, the image of that object will be a real one, will be smaller than the object itself, inverted also, and situated between the centre of curvature and the principal focus.*

And again, since the points A and A′ and the points B and B′ are two

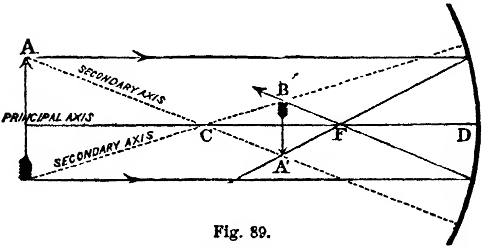


Fig. 89.

pairs of conjugate foci, it follows that an image of an object A′B′ would be formed at AB. Therefore, *if an object be placed between the centre of curvature of a concave spherical mirror and its principal focus, the image of this body formed by the mirror will be a real one, will be larger than the object itself, will be inverted, and will be situated farther from the mirror than is its centre of curvature.*

(8.) In the present figure (Fig. 90) the points A′B′ are determined in the same manner as was P′ in Fig. 88. (See 6, above).

From this figure we see that *if an object be placed between the principal focus of a mirror and the mirror itself, the image of this object will be larger than the object itself, will be upright, and will appear to be situated behind the mirror, and will therefore be a virtual image.*

The student will be able to verify these things, in some measure, by causing his face gradually to approach a concave mirror; at first his image, as presented by the mirror, will be small and inverted, then

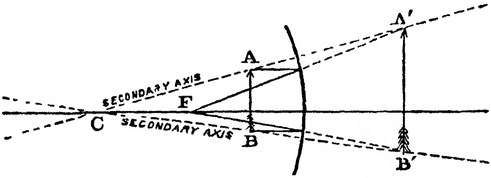


Fig. 90.

comes a moment when everything seems confused, blurred, and indistinct, and lastly he sees his image large and upright.

(9.) *Convex mirrors* never cause rays to converge; whenever, therefore, an image is formed by a convex mirror, that image is a virtual one, for it appears *behind* the mirror.

The two principles mentioned above, as enabling us to determine the formation of images by concave mirrors, apply also to their formation by convex mirrors, as we shall see immediately.

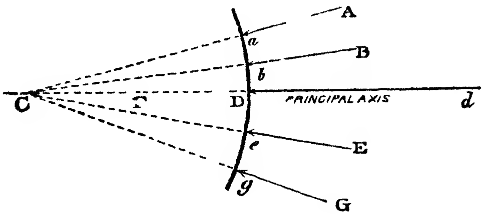


Fig. 91.

We have already seen that a ray of light, incident upon a *concave* mirror in a direction perpendicular to its surface, is reflected upon itself; the same is true of a *convex* mirror.

In the present figure the incident rays, A*a*, B*b*, *d*D, E*e*, G*g*, all strike the mirror perpendicularly; for they are each a continuation of a *radius of curvature*, *i.e.*, a line drawn from the centre of curvature, C, to the mirror. Consequently, all these rays are reflected by the way they came.

In the accompanying figure (Fig. 92) the dotted lines proceeding from C are *radii of curvature*, consequently their continuations form normals for the incident rays A*a*, B*b*, E*e*, G*g*, M*m*, N*n*; and by constructing the figure in such a way that the reflected rays, *a*A′, *b*B′, *e*E′, *g*G′, *m*M′, *n*N′, make their angles of reflection equal to those of incidence, we find that

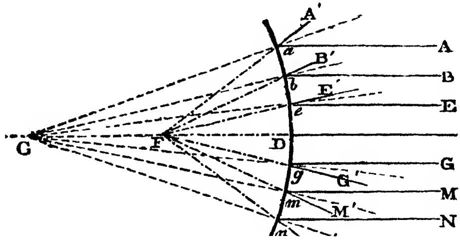


Fig. 92.

all these reflected rays appear to proceed from the point F; and therefore F is the principal focus in this as in the concave mirror, and this principal focus may be defined as that point on the principal axis from which all the rays of light incident upon the convex mirror in a direc-

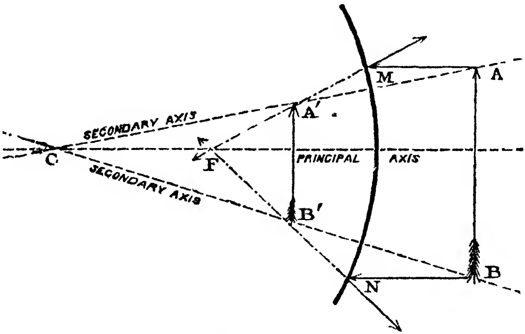


Fig. 93.

tion parallel with the principal axis *appear* to proceed, after reflection, from the surface of the mirror.

(10.) The image A′B′ of the object AB is formed by attention to the two points mentioned nearly at the end of 5 (above). By joining AC and BC we obtain secondary axes, and then taking the rays, AM, BN, which are parallel to the principal axis, we draw the lines, MF, NF, to the

principal focus, and where these intersect the secondary axes we get the points A′ and B′, and are thus enabled to describe the image A′B′.

From this we learn that *if an object be placed before a convex spherical mirror, the image formed by the mirror will be erect, smaller than the object, and virtual.*

(11.) *Spherical Aberration.*—In dealing with the reflection of light by mirrors, we have hitherto spoken of spherical mirrors in a rather loose way, for most of the propositions laid down as true of spherical mirrors are only true under special circumstances, but are strictly true of parabolic mirrors. For instance, although it is true that the rays of light which fall upon a mirror parallel to its principal axis are focussed at F when these rays lie pretty near to the principal axis, it is not true of them when they are removed some distance from that axis.

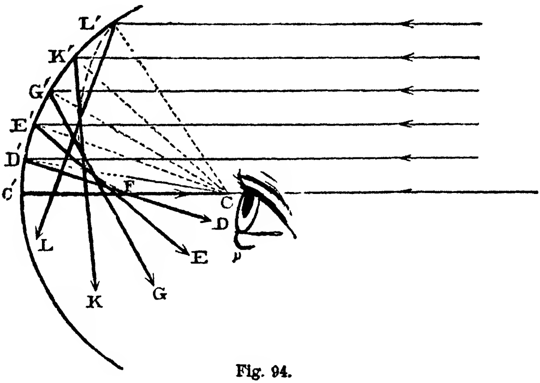


Fig. 94.

If the student constructs for himself, on a large scale, a figure corresponding to Fig. 94, and then, in order to simplify the figure, rubs out the dotted lines which are normals and the light lines which indicate the incident rays, he will have only the dark lines remaining, and these indicate the reflected rays; and he will then see that the reflected rays C′C and D′D intersect each other at the principal focus, F; that D′D and E′E intersect at a point *near* the principal focus; that E′E and G′G intersect at a point still near the focus, but not so near as in the last case; that G′G and K′K intersect at a point comparatively *distant* from F; and that K′K and L′L intersect at a still more distant point.

Now it is possible for an eye situated at C, that is, roughly speaking, *on the principal axis*, to receive the rays C′C and D′D (and all the rays intermediate between them, and of which there will, of course, be a great number in any actual case); to such an eye there will appear to be a

bright spot at F, where these rays intersect, in fact, the rays will appear to come both from F.

In the same way, an eye so situated as to receive any other two of the reflected rays will see bright spots at *their* point of intersection, and therefore an eye so situated as to receive *all* these reflected rays will see bright spots at *all* their points of intersection.

Now, concerning these points of intersection, two things may be noted:

1st. That a great many of them lie close to the principal focus, F, and that those which do so lie close to F are the points of intersection of those reflected rays whose incident rays struck the mirror near to C′, and whose incident courses therefore lay near to the principal axis.

2d. That through these points of intersection a curve might be drawn, whose cusp should be situate at F. (See the line drawn thus —.—.—.— in the figure.) Such a curve is called *a caustic curve.*

(12.) The accompanying figure is intended to show that the same two

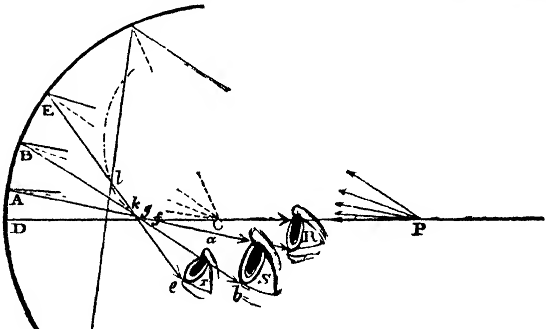


Fig. 95.

things are true of rays diverging from a point, P, situated on the principal, axis, that we have just shown to be true of rays parallel to that axis, viz.:—

1st. That there is a crowding together of points of intersection at one point, *f*, the points thus crowded together being the intersections of rays whose points of incidence on the mirror lie near D, the centre of the mirror.

2d. That the points of intersection, f,g,k,l, all lie in a caustic curve as shown by the line thus —.—.—.—.

(13.) From Fig. 95 it is evident that an observer stationed at R will see an image of P at *f*, an observer at S will see it at *g*, and an observer at T will see it at *k*, &c.; in short, the position of the image of P will vary according to the position of the observer.

It is also evident from the same figure that the image seen at a point near *f* will be brighter than one seen at a greater distance from *f*, because of the greater number of rays which *practically* converge on *f*; in fact, it is usually assumed that all the rays incident upon the mirror within 8° of the circle whose centre is D are focussed at *f*.

(14.) The caustic curve is evidently the locus of the points of intersection of rays reflected from a mirror; but whenever these rays pass or appear to pass through one point the caustic then is simply one bright spot, thus, "the caustic of an *ellipse*, the luminous point being in one focus, is the other focus; of a *parabola*, for rays coming parallel to the axis, it is the focus. The caustic of a plane mirror is the point as far behind the mirror as the luminous object is in front of the mirror on the same normal."—(*Optics, by Airy.*)

(15.) *An experimental illustration of the formation of a caustic curve* is exhibited in Fig. 96, in which the rays of a candle falling upon the concave surface of a tumbler, produce upon the surface of the milk contained in the tumbler a curve of bright light: this is a caustic curve. It will be seen that the cusp is somewhat blurred in the actual experiment; this, and, in fact, the whole appearance of the curve, is due to the aberration of light by the concave spherical surface from which it is reflected.

Fig. 96.

Similar appearances may be produced by causing the rays of the sun, or of a lamp or candle, to fall upon a piece of watch spring bent in the form of a semicircle and resting upon a white surface; the concave part of a bright spoon also will produce similar appearances upon a tablecloth.

(16.) *The reflection of sound by curved surfaces* is regulated by the same laws which govern the reflection of light by curved mirrors, and may be thus illustrated:—

In Fig. 97 the sound waves proceeding from a watch are reflected into

an ear-trumpet, and it is in accordance with what we have learned respecting the reflection of light, to suppose that a person using the ear-trumpet at T will hear the tickings of the watch with greater distinctness than he would at the point P, although the latter point is actually nearer the watch than is the other point.

Also, since the points T and F may be regarded as *acoustic conjugate*

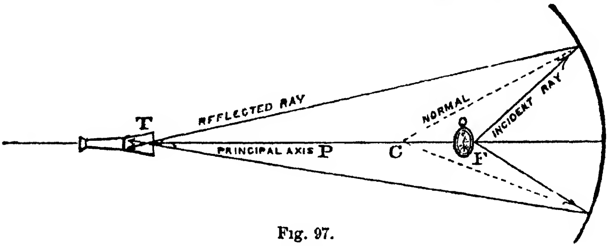


Fig. 97.

foci, it follows that if the positions of the watch and the trumpet be interchanged, a person using the trumpet at F will distinctly hear the tickings of the watch at T.

In Fig. 98 the tickings of the watch, W, placed at the principal focus of a concave mirror, are reflected in directions parallel with the joint

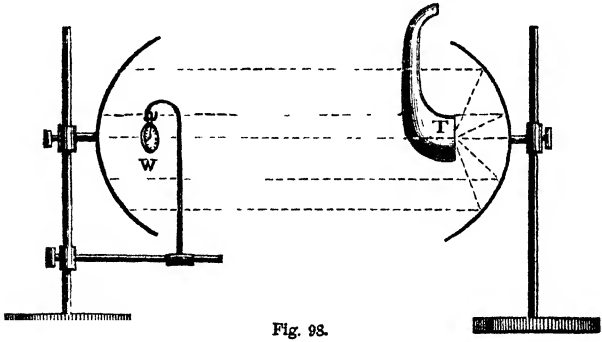


Fig. 98.

principal axis of the two mirrors, and are collected by the ear-trumpet, T, placed at the principal focus of the other mirror.

Here, again, W and T may be regarded as *conjugate foci*, and therefore the positions of the watch and the trumpet are interchangeable without interference with the effect produced.

Buildings, sometimes by accident and sometimes by design, are so constructed that sound waves are reflected in such manner as to produce

curious results. For instance, there is in Paris a room whose ceiling is elliptical; the consequence is, that slight whispers proceeding from a person standing in one of its foci are distinctly heard by a person standing in the other focus, although perfectly inaudible to persons stationed between them.

(17.) *The reflection of radiant heat* may also be shown by this apparatus. A red-hot ball is hung at W, and its heat rays being concentrated at T ignite a piece of phosphorus or a quantity of gunpowder placed there for that purpose.

That radiant heat is reflected in a vacuum as well as in air, was proved by Sir Humphrey Davy by means of an experiment somewhat similar to the one just described. He used reflectors, as in figure 98, and, placing them in vacuo, he fixed a delicate thermometer at T, and at W he arranged a platinum wire rendered incandescent by means of a galvanic current, and he found that the mercury rose several degrees.

Application is made of the reflection of radiant heat in the construction of "Dutch ovens" and roasting "jacks;" these are so constructed that nearly all the heat incident upon them is reflected upon the meat to be roasted.

N.B.—If a concave mirror be placed so as to receive rays from the sun, a piece of paper placed in its principal focus will be set on fire by the reflected heat.

22. Refraction.

(1.) *Whenever a wave which is travelling through a medium of a certain density becomes incident obliquely upon another medium of a different density, the course of that wave is diverted towards the normal if the new density be greater than the former, and from the normal if the new density be less than the former.*

Thus, a wave which has been travelling through air changes its direction when it becomes incident upon a body of water, and takes a new course lying nearer the normal than its former course did.

In the accompanying figure (Fig. 99) the incident rays, PO, PO′, proceeding through air from the luminous point, P, become the refracted rays, OP′, O′P″, proceeding through water.

The law of refraction may be understood from the construction of this figure. Let the student draw the rays PO, PO′, and then with centres O and O′ and distances OP and OP′ respectively, construct the two circles indicated in the figure. From P let fall the perpendicular PR, divide OR into four equal parts, and take OS equal to three of these, so that

$$\frac{OR}{OS} = \frac{4}{3};$$

then from S let fall the perpendicular SP′ to cut that circle whose centre

is O; join OP′. Then OP′ is the direction of the refracted ray incident at O.

Similarly, divide O′R into four equal parts, take O′S′ equal to three of these, and draw the perpendicular S′P″ to cut the circle whose centre is O′. Join O′P″, then O′P″ is the direction of the refracted ray incident at O′. The chief thing here to be noted is that

$$\left.\begin{array}{ll} & \dfrac{OR}{OS}=\dfrac{4}{3} \\ \text{and} & \dfrac{O'R}{O'S'}=\dfrac{4}{3} \end{array}\right\} \therefore \frac{OR}{OS}=\frac{O'R}{O'S'}$$

The value $\frac{4}{3}$ called *the index of refraction* is true always when air and water are the media of propagation.

N.B.—It must be noted,

1st. That when light is incident upon the surface of a body of water in the manner shown in the figure, a portion of it is *regularly*

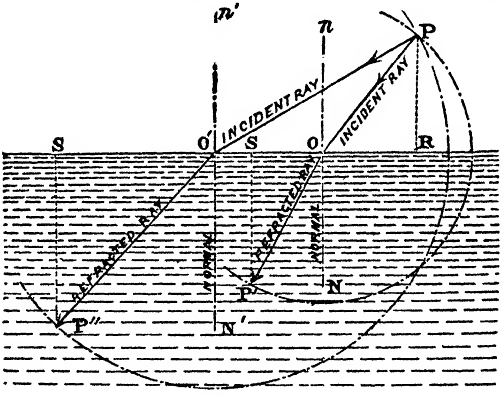


Fig. 99.

reflected, another portion is *irregularly reflected* (*i.e.*, *dispersed*), and the remainder enters the water and undergoes refraction.

2d. That of these three portions, the one which is regularly reflected and the one which is refracted both continue in the plane of their incident ray.

3d. That the portion regularly reflected may meet the eye of an observer and give rise to the formation of an image as in a plane mirror. (See Fig. 100.)

4th. That when light which has been passing through one medium becomes incident upon another medium, the value of the index of refraction changes with a change of the media concerned, but not with a change in the angle of incidence. For example, if glass be substituted for water in Fig. 99, the index of refraction will be $\frac{2}{3}$ whatever be the angle at which the ray which has been propagated through the air may strike the surface of the glass.

Fig 100.

5th. That rays of light originating at P′ and P″ (Fig. 99), and taking the directions P′O, P″O′ respectively, will be refracted in the directions OP, O′P respectively, and will thus meet in P.

This *law of refraction*, viz., that with the same two media of propagation the value of $\frac{OR}{OS}$ is constant, may easily be shown to be in conformity with what is called the "*Law of Sines*," as follows:—

In the accompanying figure the line AC is *the perpendicular*, and the

line AB is *the hypotenuse* of the angle ABC, and it may be proved by geometry that *while the angle ABC remains unchanged, the relation which*

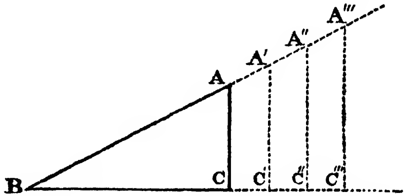


Fig. 101

AC bears to AB is constant; this may be otherwise expressed, thus—

$$\frac{AC}{AB} = \frac{A'C'}{A'B} = \frac{A''C''}{A''B} = \frac{A'''C'''}{A'''B}$$

And the value of this fraction $\frac{AC}{AB}$ is called *the sine of the angle ABC.*

Now in Fig. 99 we have

$$POn = \text{the angle of incidence, and}$$
$$P'ON = \text{the angle of reflection,}$$

and therefore

$$\textit{the sine of the angle of incidence} = \text{the sine of the angle } POn = \frac{Pn}{OP} = \frac{RO}{OP} \ldots\ldots\ldots\ldots\text{(i.)}$$

and, *the sine of the angle of reflection* = the sine of the angle P′ON

$$= \frac{P'N}{OP'} = \frac{SO}{OP'} = \frac{SO}{OP} \ldots\ldots\ldots\ldots\text{(ii).}$$

Therefore, arranging the values (i.) and (ii.) we get the following fraction :—

$$\frac{\text{the sine of the angle of incidence}}{\text{the sine of the angle of reflection}} = \frac{\frac{RO}{OP}}{\frac{SO}{OP}} = \frac{RO}{SO}$$

But experiments show us that this fraction $\frac{RO}{SO}$ is a constant quantity; it follows then that

$$\frac{\text{the sine of the angle of incidence}}{\text{the sine of the angle of reflection}} = \text{a constant quantity.}$$

This constant quantity is called the *Index of Refraction*, and, as before stated, is, in the case of air and water, $\frac{4}{3}$. It may be defined as *that numerical quantity by which the angle of Refraction must be multiplied to find the angle of incidence.*

(2.) In Fig. 102 let the arrow be the base of the triangle, ABC, then it can be proved by geometry (Euc. 1. 21) that the angle BAC is less than

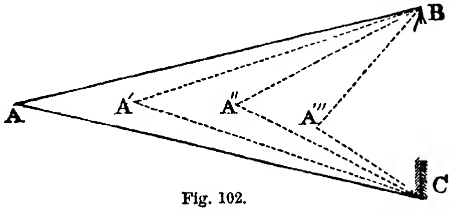


Fig. 102.

BA′C; that BA′C is less than BA″C; and that BA″C is less than BA‴C; in a word, *if from the ends of one side of a triangle there be drawn two right lines to a point within the triangle, these shall contain an angle greater than that which was originally opposite the side from whose ends the lines are drawn.*

Now we know that the farther we remove ourselves from an object the smaller that object appears to us, and if we take A‴, A″, A′, A (Fig. 102), to represent successive positions of the eye of an observer placed before the object BC, we see that the angle enclosed between the ray coming from

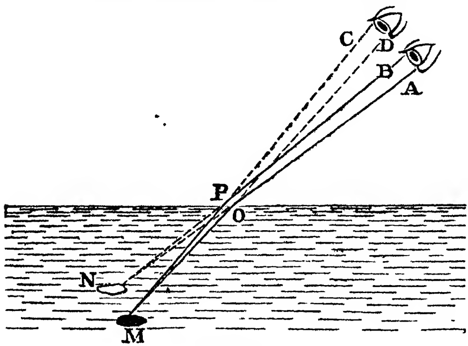


Fig. 103.

one extreme end of the object and that coming from the other extreme end *decreases* as our distance from the object *increases.* This angle is called *the visual angle*, and that the apparent size of an object increases as this angle increases, and decreases as this angle decreases, may be

demonstrated by the fact, that if we interpose between our eye and an object a piece of glass so shaped as to increase the visual angle we shall thereby increase the apparent size of that object. This is the principle of the simple microscope, as we shall see hereafter.

(3.) In Fig. 103 the two rays MO, MP are refracted as OA, PB, and thus *appear* to come from the object N. For the eye at AB judges that the ray OA has come to it in the direction NOA, and that the ray PB has come to it in the direction NPB, and, therefore, that the object from which these rays proceed is at N, where these directions intersect.

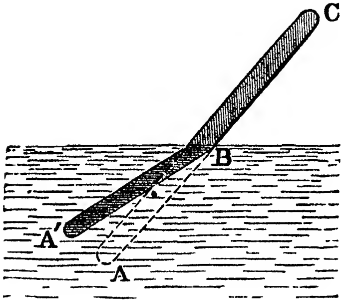


Fig 104.

Now it can be proved that the angle BNA is greater than the angle CMD; therefore (by 2, above, see Fig. 102) the image of the object at N, that is as it appears when viewed through the *water*, is larger than the same object at N, that is as it would appear when viewed through the *air* alone.

But as this effect is produced in all objects seen in this manner through water, it follows that all the objects at the bottom of the water will appear larger than they would if viewed through the air alone. Now the nearer a thing is to us the larger it appears; therefore, since all the objects at the bottom of the water appear larger than they really are, we naturally judge that the whole bottom of the water is nearer to us than it really is; in other words, the effect of the refraction of light due to water is to make the water appear shallower than it really is.

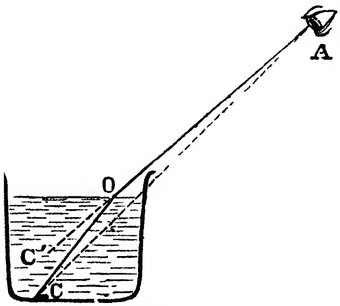


Fig. 105.

(4.) In Fig. 104 is shown the appearance which is produced when a stick is thrust obliquely into a body of water. The end A of the stick ABC appears to be lifted to the position A′, and thus the stick appears to be bent at B. In other words, the actual stick ABC appears as the object A′BC.

(5.) In Fig. 105, C represents a coin at the bottom of a basin. Let this

basin at first be empty, then a ray proceeding in the direction CA will be intercepted by the edge of the basin, as shown by the dotted line in the figure; therefore the coin C will not be visible to the observer at A.

Now let water be gradually poured into the basin, then the coin will ultimately become visible, for, as shown in the figure, the ray CO will be refracted to A, and thus the observer at A will receive the ray COA, and will see the coin apparently at C′.

(6.) In Fig 106 is represented a portion of the earth surrounded by the atmosphere, the increasing density of which is indicated by the increasing nearness of the surrounding circles. S is a star from which the ray S*m* proceeds. This ray after undergoing repeated refractions (as shown by the dotted lines at *m a b c*), at last reaches the earth at the point O; at

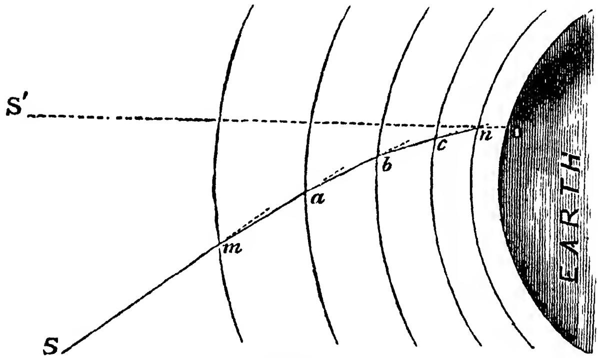


Fig. 106.

the moment of reaching O, the ray is proceeding in the direction *n*O; consequently the star appears to be at S′. In this case the refraction of the light is due to the difference in the densities of the different layers of the atmosphere, and it will be observed that its effect is to raise the apparent position of the star. It thus happens that a star whose real position is below the horizon may be rendered visible to an observer.

It should be noted also that the line *mabcn*O forms a curve.

(7.) **Critical Angle.**

In Fig. 99 a ray of light proceeding from P″ to O′ would then take the course O′P. Here we have the angle of incidence P″O′N′ smaller than the angle of refraction *n*′O′P; and it is always true that when a ray passes from any medium into another having less density, it makes its angle of incidence less than its angle of refraction. Consequently, in every such case there must be a certain angle of incidence, which is less than a right angle, and yet has its angle of refraction equal to a right angle. Let

MOB (Fig. 107) be this angle; then the refracted ray takes the course ON, that is, it skims the surface of the water. It is now clear that any angle of incidence larger than MOB, say ROB, must have an angle of refraction greater than a right angle; in such a case the ray does not enter the lighter

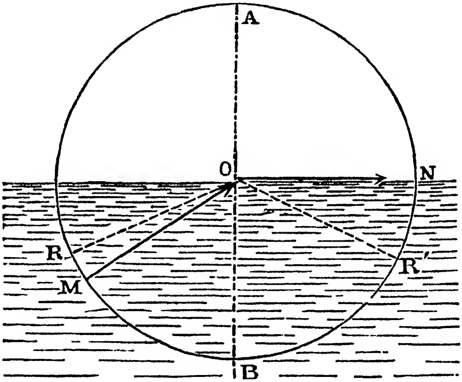


Fig. 107.

medium at all, in fact, there is now no refraction at all but reflection takes place, and that according to the ordinary laws of reflection, so that the ray RO is reflected to R′, the angle ROB being equal to R′OB.

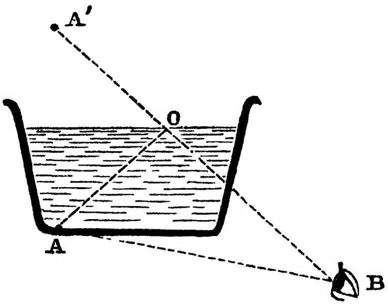


Fig. 108.

The angle MOB being that at which refraction ceases is called *the Critical Angle*, and the reflection, which takes place at the angle ROB, is called *Total Reflection*, because *all* the incident light is in this case reflected back into the medium wherethrough it has come.

From water to air the Critical Angle is 48° 35′; from glass to air it is 41° 48′.

(8.) **Total Reflection.**

In Fig. 108 is represented one of the effects of Total Reflection; an image of A is seen A′. The vessel containing the water is of glass; con-

sequently the observer at B can see two images of the object A, viz., one due to the direct ray AB, the other due to the reflected ray AOB.

N.B.—Some curious effects may be observed when a spoon is placed in a tumbler of clear water and then looked at from below the tumbler.

(9.) **Mirage.**

In Fig. 109 is represented a curious effect produced by refraction and total reflection.

In hot sandy regions it frequently happens that the layers of air near the soil are hotter than those above them; these lower layers are then less dense than the higher ones. Therefore a ray of light proceeding from the point P towards the earth enters layers whose density con-

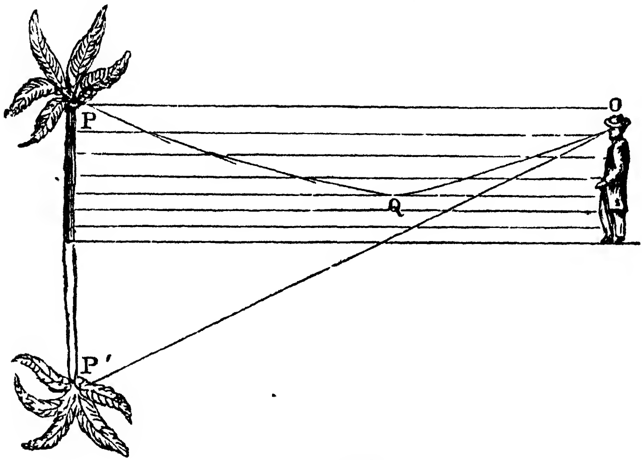


Fig. 109.

tinually decreases; its course, therefore, is one which makes a greater and greater angle with the normal (in other words, the angle of incidence continually increases), till *the critical angle* is at last reached, and their total reflection takes place as at Q (Fig. 109). After this the ray begins to rise, and at last reaches the eye of the observer at O, after having undergone a series of refractions which are the exact opposite of those it experienced in proceeding from P to Q. The ray at the moment of reaching O *appears* to come from P′; the observer consequently sees an image of P at P′: an effect is then produced similar to that shown in Fig. 109.

(10.) Other very strange effects are sometimes produced by refraction; in order to understand these, however, it is necessary to remember that *the atmosphere itself is but very little heated by the passage of the sun's rays through it;* the differences in its temperature are usually produced by its contact with heated bodies. Thus, when the sun shines on woods, and fields, and sandy deserts, and bodies of water, all these become heated in consequence, and then the air in contact with them becomes heated also. But as these bodies do not all become hot at the same rate, and, further, as they do not all part with their heat with the same readiness, it follows that the different portions of the air in contact with these different bodies become heated to different degrees. Under these circumstances refraction takes place as in (9) above (Fig. 109), though not always in that direction. For example, images of distant shores are sometimes seen by sailors. These images appear as lifted into the air, and are probably due to the temperature of the air resting on the land being greater than that of the air resting on the sea. Sportsmen have also related stories of their having shot several times at an animal which appeared quite within their range, and yet to have missed it, the reason probably being that in consequence of refraction they were deceived as to its position.

(11.) **Prisms.** Remembering the law of Refraction enunciated in § 22 above (page 93) we can easily see—

1st. That when a ray of light impinges upon a sheet of glass, whose faces are parallel to each other, as in Fig. 110, the direction which the ray takes on leaving the glass is parallel with that it pursued when approaching the glass, for the deviation due to refraction at one face just counterbalances that due to the refraction at the other face.

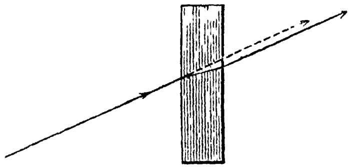
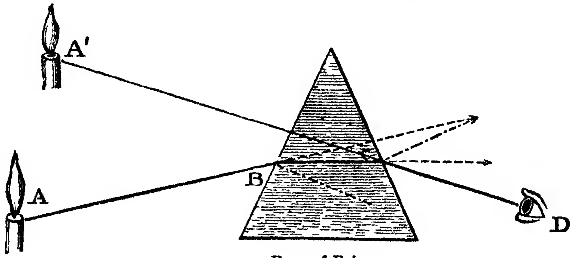


Fig. 110.

2d. That if in Fig. 111 be represented a transverse section of a three-sided piece of glass called *a prism*, then the ray of light starting from A will be refracted to C and then again to D; in short, *the effect of placing such a prism in the path of a ray will be to cause that ray to be refracted towards the base of the prism, both when entering and also when leaving the prism.*

In this Figure the lines dotted thus ------ signify the direction in which the ray moves before refraction; the lines dotted thus —·—·—·— signify the normals at the points of refraction. The student will carefully notice that the glass being denser than the surrounding air the refraction at B is *towards* the normal, but at C it is away *from* the normal.

From the figure it is clear that an observer at D will see an image of A at A′, *i.e.*, farther from the base than the object itself.



Base of Prism.

Fig 111.

N.B.—1st. In a prism the angle opposite the base is called *the refracting angle*, and the edge where the two refracting surfaces meet is called *the refracting edge*, or *the edge*. Thus the refracting edge and the refracting angle are both opposite the base.

2d. Prisms are not all made of glass: they must consist of a transparent substance whose refractive power is different from that of the air. Its density is usually, but not necessarily, greater than that of the atmosphere.

(12.) **Lenses** are usually made of glass, and are used to cause rays of light either to converge or to diverge. Their power to cause these changes in the direction of luminous rays depends upon—

1st. The nature of the glass or other material of which they are composed;

2d. The curvature of their surfaces.

There are six kinds of lenses usually employed in optics; transverse sections of these are represented in Fig. 112.

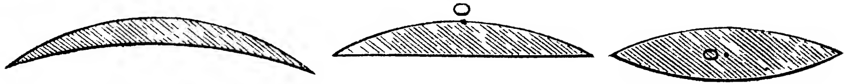
It will be noticed that all the *Converging Lenses* are thicker at their centres than at their borders, but all the *Diverging Lenses* are thicker at their borders than at their centres.

In Nos. 1, 3, 4, 6 both the faces of the lenses are spherical. The centres of the spheres of which these faces are parts are called *Centres of Curvature;* the line joining these is called *the Principal Axis*. In Nos. 2 and 6 the principal axis is a line drawn from the centre of curvature at right angles to the plane surface of the lens.

In every lens there is a point called its *Optical Centre*. This point is always situated on the principal axis, and its position in four of the different lenses is marked in Fig. 112 by the points O. All secondary

I. CONVERGING LENSES.

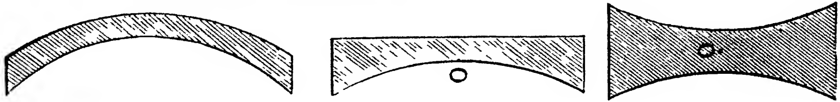
3. Concavo-Convex, or Converging Meniscus. 2. The Plano-Convex. 1. The Double-Convex.



These lenses are called *Converging* because, as we shall see hereafter, they usually cause the rays which leave them to converge towards a point before them, *i.e.*, on that side of the lens which is opposite to the starting-points of the rays.
In the following pages we shall study the properties of the first only of these, because the properties of all the three are similar in kind though differing in degree.

II. DIVERGING LENSES.

6. Convexo-Concave, or Diverging Meniscus. 5. Plano-Concave. 4. Double-Concave.



These lenses are called *Diverging* because, as we shall see hereafter, they cause the rays which leave them to appear to diverge from an imaginary point behind them, *i.e.*, a point on the same side of the lens as the starting-point of the rays.
In the following pages we shall study the properties only of the first lens of this group, because the properties of all the three are the same in kind though different, of course, in degree.

Fig. 112.

axes also pass through this point: hence its importance. In each meniscus the optical centre lies outside the lens altogether. The peculiar property of this point is that all rays, which in their course through a lens traverse its optical centre, leave the lens in a direction parallel with that in which it approached the lens; and, *vice versâ*, every ray whose course on leaving a lens is parallel with that by which it reached the lens, must have passed through the optical centre of that lens.

The Real Focus of a lens is that point towards which the rays, which in any particular case traverse it, are refracted. *The Virtual Focus* of a lens is that point from which the rays, which in any particular case traverse it, appear to proceed.

(13.) We have shown above that the effect produced by placing a prism in the path of a ray of light, is generally to cause that ray to take a direction which is inclined to the base of the prism.

Let the dark outline of Fig. 113 represent the shape of a piece of glass. Then the triangles ABC, ADE, AMN, and the corresponding triangles A′B′C′, A′D′E′, A′MN, may be taken for six prisms, and, therefore, the six rays Pa, Pb, Pc, Pa', Pb', Pc', will all be refracted towards the line PP′; and an experiment would show that all these rays would intersect each other in a point P′ situate on the line PP′, which line itself passes through the glass without undergoing refraction.

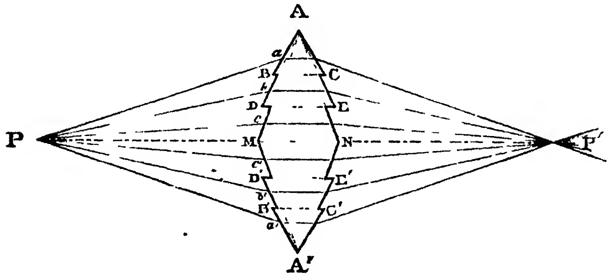


Fig. 113.

Now this figure has been so constructed that all the points A, B, D, M, D′, B′, A′, are in the circumference of a circle; also, the points A, C, E, N, E′, C′, A′ are in the circumference of another circle. If these circles be described, then (omitting unnecessary lines) we shall have the figure shown in Fig. 114; a piece of glass whose transverse section corresponds to this figure is called *a double-convex lens*. The action of such a lens is to bring to a focus, as at P′, all the rays falling upon it from a luminous

point P. In order to see clearly that this is so, the student must carefully compare Figures 113 and 114.

Arguing thus, from the properties of a prism, we have thus found that *the action of a double-convex lens is to bring all the rays incident upon it from one point* P, *towards another point* P′ *situated on the opposite side of the lens.*

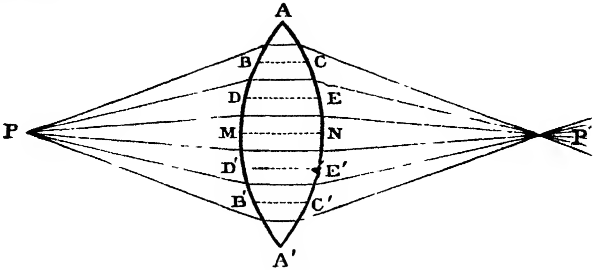


Fig. 114.

(14.) Let us now investigate the subject in another manner, and see whether we obtain a confirmation of the results obtained.

In Fig. 115 take the line PP′, and with centre C describe the arc AaA'; also with C′ as centre describe the arc $Aa'A'$. Then the figure $Aa'A'aA$ may be taken to represent the transverse section of a double-convex lens, and the normals marked in the figure are ascertained as in Figs. 85, 86,

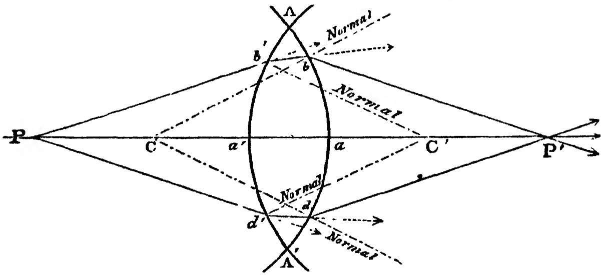


Fig. 115.

and 92. Then the ray Pb' is refracted *to* the normal at b', and consequently takes the course $b'b$; at b it is refracted *from* the normal, and consequently takes the course bP′.

The course of the ray Pd' dP′ can similarly be traced from the figure, and in this case, as in Fig. 113, the effect of the lens is to cause both the rays to deviate towards the line PP′.

It is evident from the figure that an image of the point P will be formed at P′: this image will be a *real* one, because it is formed by the actual intersection of actual, though refracted, rays.

N.B.—As in the case of mirrors, the normals are drawn from the centres of curvature. [See (2) page 82.]

(15.) In Fig. 116, with centre C describe the arc *bd′b′*, and from centre C′ describe the arc *ada′*; describe the radii C′*a* and C′*a′*; describe also the radii C*b* and C*b′*, and produce them to B and B′. Then the four lines C′*a*, C′*a′*, *b*B, and *b′*B′ are normals.

An examination of the figure will then show that the ray P*a* will be refracted into the course *ab* on *entering* the lens, and then into the course *b*F on leaving the lens. Similarly the ray P′*a′* proceeds first to *b′* and then to F.

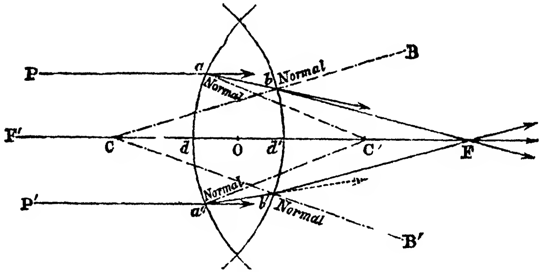


Fig. 116.

Also the ray CC′, which is called the *Principal Axis* of the lens, passes through F. But the rays P*a*, P′*a′* proceed to the lens in directions parallel to CC′. Therefore, we have the three parallel rays P*a*, P′*a′*, and CC′ all meeting in one focus F. We should also find that all other rays parallel with these and falling upon the lens would also be refracted to pass through F. *Therefore* F *is called the* principal focus *of the lens, because it is that point on the principal axis through which pass* all *the rays that are incident upon the lens in directions parallel with that axis, OR;* since the positions are reversible, we may say that F *is the principal focus of the lens, because all the rays* (F*b*, F*d′*, F*b′*) *which proceed from it to the lens are so refracted while passing through the lens, as to leave it in directions which are parallel to its principal axis.*

N.B.—In Fig. 116 the lines C*b*, C*d′*, C*b′*, C′*a*, C′*d*, C′*a′* are called *Radii of Curvature.*

(16.) If now the points *a* and *a′* remain fixed, while the points P and P

are brought gradually nearer the principal axis, the point F will move gradually farther and farther to the right, till at last, when the lines Pa, P$'a'$ cross each other at the point F$'$, the lines bF, b'F will have separated themselves from the principal axis, and will have appeared as rays leaving the lens parallel to that axis. We see, then, that as the lines aP, a'P$'$ approach each other towards the left, the lines bF, b'F separate from each other towards the right, and *vice versâ*.

(17.) In Fig. 117 the ray Pa is parallel with the principal axis, and is consequently refracted to F$'$, the principal focus. And the ray Fa proceeding from the other principal focus, F, leaves the lens as $a'p$, *i.e.*, in a direction parallel with the principal axis. Therefore the ray P$'a$, falling between Pa and Fa, will, on leaving the lens, pursue some such course as ap', lying between aF$'$ and $aa'p$. Also, the ray P$''a$, falling between P$'a$ and Fa, will, on leaving the lens, pursue a course ap'', lying between ap' and $aa'p$. Lastly, the ray P$'''a$, lying nearer the lens than Fa,

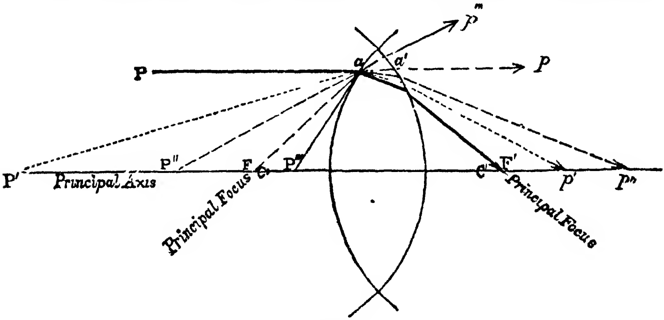


Fig. 117.

will, on leaving the lens, take a course ap''' lying on that side of $aa'p$ which is opposite to ap''. In the diagram, the whole courses of these rays are separately indicated by distinctive lines, and the student will observe that *as the point from which the ray proceeds is made to approach nearer and nearer to the lens, the direction of its refracted course* (i.e., *its course after leaving the lens*) recedes *further and further from the principal axis*. This law holds good for all cases in which convex lenses are employed.

(18.) So far we have considered only the case in which the rays proceed from a single luminous point. Let us now consider the case in which the light proceeds from a luminous body of appreciable dimensions.

In Fig. 118 let the object AB be placed a little before F, the principal focus of the lens. In order to find the position of the image, join A to O, the optical centre of the lens, and produce AO indefinitely to A′. In a similar manner describe the line BOB′. These are *Secondary Axes*, and on these lines will the rays proceeding from A and B be respectively focussed. But in order to ascertain where *all* the rays leaving A will be focussed, it is only necessary to find where any one of them will cross its proper axis. Now we know that the ray A*m*, parallel to FF′, must pass through F′; therefore joining *m*′F′ and producing it in the same direction we cut AOA′ at A′. Therefore an image of A will be formed at A′.

In a similar manner we find that an image of B is formed at B′; therefore the image of AB is A′B′.

We thus see that *if an object*, AB, *be placed immediately before the principal focus of a double-convex lens, the image there of* A′B′ *is real, is inverted, is larger than the object itself, and is more distant from the lens.*

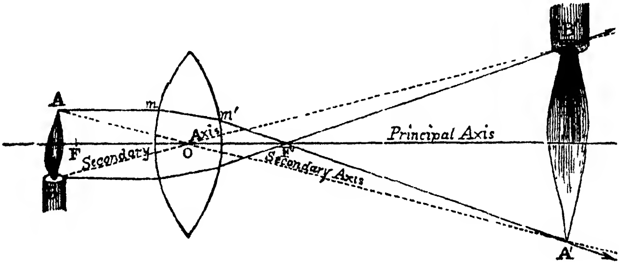


Fig. 118.

And as the positions of the object and its image are in all such cases interchangeable, it is clear that *if an object* A′B′ *be placed before a double-convex lens at a convenient distance, a real and inverted image will be produced on the other side of the lens, not far from its principal focus, but rather farther from the lens than is that focus.*

N.B.—In order to observe the images the observer must place his eye at the places of their formation, or he may place a white screen there, and then observe the image depicted upon it.

(19.) In Fig. 119 the object AB is placed between the principal focus and the lens. We find that when the ray A*m* leaves the lens as *m*′F it pursues a course which will never bring it into contact with its own secondary axis, AO produced. But if this axis and the ray *m*′F*m*″ be produced backwards, that is, to the left, these two lines will meet at A′. Therefore the ray *m*′F, which *really* proceeds from A, *appears* to come from A′.

In a similar manner, the ray $n'F$, which really comes from B, appears to come from B′. Therefore an image of the object AB is seen at A′B′. This image is *virtual* because it is not formed by actual rays. It is, moreover, on the same side of the lens as is the object itself; this alone is sufficient to proclaim its *virtual* character.

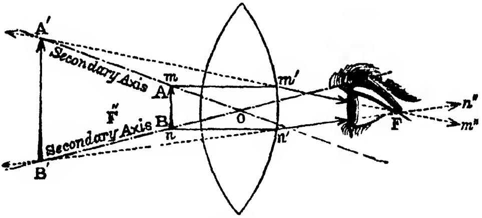


Fig. 119.

From this figure, then, we see that *if an object be placed between the principal focus of a double-convex lens and the lens itself, an upright, virtual image of that object will be formed at a greater distance from the lens, and this image will be considerably larger than the object itself;* hence, a double-convex lens is frequently called a *Simple Microscope.*

(20.) In Fig. 120 are represented five rays incident upon a double-concave lens, one of which proceeds along the principal axis, and therefore passes through the optical centre, and so emerges on the opposite side of the lens without change of direction.

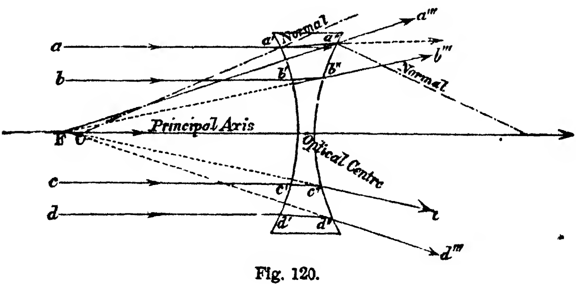


Fig. 120.

In the case of the ray $aa'a''a'''$ its refraction at a' is *towards* the normal, at a'' the refraction is *from* the normal. In both cases, however, the

effect of the refraction is to deflect the course of the ray away from the principal axis.

A similar effect is produced in the cases of the remaining rays $bb'b''b'''$, $cc'c''c'''$, $dd'd''d'''$, so that all the five rays *appear* to proceed from the point F. This point is therefore a *virtual focus.* It is also evidently one of principal foci of the lens, seeing that the rays to which it is the focus are those which fall on the lens parallel with the principal axis.

N.B.—The normals in this, as in other cases, are drawn from the centres of curvature. [See (2) page 82.]

(21.) In order to make himself thoroughly acquainted with the action of concave lenses the student should draw for himself a series of diagrams similar to those numbered 113 to 119 in this manual. We can only here find space for one of them, viz., the one which shows how the image of an object of sensible dimensions is produced by a concave mirror.

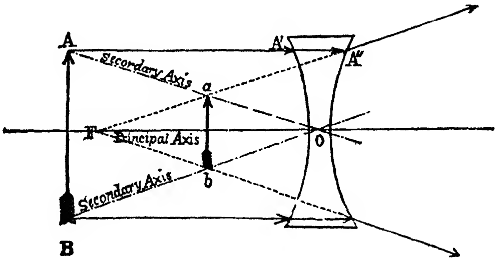


Fig. 121.

In Fig. 121 the point O is the optical centre of the lens, F is its principal focus. Let it be required to find the image of the object AB.

Join AO and BO; then these are the secondary axes of the lens for the points A, B, respectively; then all the rays emergent from A and incident on the lens must be focussed somewhere on AO, and, similarly, all those from B will be focussed somewhere on BO. Now, as shown in the diagram, the ray AA′, which is one of the rays emergent from A, appears to pass through F; therefore the point of intersection, *a*, will be the position of the image of A. Similarly, *b* will be the position of the image of B. Therefore *ab* is the image of AB. *This image is virtual, upright, and smaller than the object itself.*

N.B.—It must be carefully noted that while the image produced by a convex lens may be either virtual or real, either upright or inverted, and either larger or smaller than the object; that produced by a concave lens is always virtual, always upright, and always smaller than the object.

(22.) The Magic Lantern.

In Fig. 122, R is a concave reflector fastened to the back of a tin box; F is a lamp placed in the principal focus of R, and whose rays, therefore, leave R parallel to its principal axis (see fig. 98). These rays, as shown in the figure, are caught upon a convex lens, M, by which they are concentrated upon a glass slide, whose faces are parallel and on which some coloured object—an arrow, AB—is depicted.

Let F′ be the principal focus of the lens M, and then let a double-convex lens, N, be placed rather to the right of F′; then the rays, instead

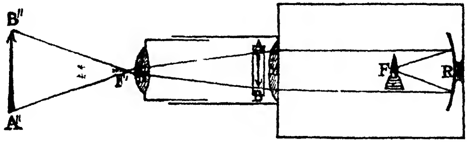


Fig. 122.

of pursuing their courses, as shown by the dotted lines, will be so refracted as to form a larger and inverted image on a screen placed in the path of the rays to the left of N; let this image be A″B″. (Compare fig. 118.)

Such an apparatus as this shown in Fig. 122 is called a *magic lantern*. It is evident that in using it the slide AB must be placed upside down, if an upright image of the object is to be produced. The front part of the apparatus—that is, that part which carries the lens, N—is constructed after the manner of a telescope, so that we can slide it in or out according to the distance of the screen to the left.

(23.) The Refraction of Sound. In Fig. 115 let a watch be placed at P, and let the double-convex lens be replaced by one of those thin india-rubber balloons which children use as toys. Then if this balloon be filled with carbonic acid gas, which is heavier than common air, it will act as a lens; and it will then be found that there is a certain point on the right-hand side of the balloon, and situated on its principal axis, at which the sound is very distinctly audible, although it cannot be heard at points immediately above or below it, or to the right hand or to the left. Evidently, then, the sound waves are focussed at that particular point.

If the lens be filled with hydrogen gas, which is much lighter than common air, it will not be possible to find this focus; the light gas in this case produces effects similar to those of a concave lens, and the virtual focus thus formed cannot, of course, be detected.

(24.) Spherical Aberration of Lenses. As in treating of mirrors, so in treating of lenses, we have found it convenient to take for granted

certain things which are not *exactly* true. Among these we have assumed that all the rays incident in any particular case upon a spherical lens, are by it focussed to one point; this is only true when the angle formed by joining the edges of the lens to its centre of curvature does not exceed 12°. This angle is called the *Aperture of the Lens;* and when this aperture exceeds the limit abovementioned, the rays, instead of being focussed to one point, touch a curved surface called *a Caustic.* The cusp of this caustic is the point we have hitherto assumed as *the focus.* It will readily be understood that this *caustic of refraction* is closely allied to the *caustic of reflection* in the case of mirrors (Fig. 96), and that this *spherical aberration of a lens* is also of a nature precisely similar to the *spherical aberration of a mirror* previously treated of.

23. Properties of Matter. In order to the better understanding of some of our succeeding remarks, it is necessary that we should here give a brief account of the more important properties of matter.

(1.) *Matter is porous—i.e.,* it contains tiny spaces between the tiny particles which compose it; for all matter, however hard and solid it may appear, is probably composed of very minute particles which do not actually touch each other. That matter *is* porous, is proved by this other fact that

(2.) *Matter is compressible—i.e.*, a given weight of matter, whether it be solid, liquid, or gaseous, is capable of being forced into a smaller space than that it was occupying. This is rendered possible by the existence of the pores or interspaces of which we just now spoke.

(3.) *Matter is elastic—i e.*, when compressed into a smaller volume, it exerts a constant tendency to return to the volume it occupied before compression. This is, of course, an effect of the presence of heat, and probably other repulsive forces, acting between its particles (see page 7).

(4.) The atoms of *matter are impenetrable—i.e.*, no two atoms of matter can occupy the same point of space at the same moment of time. When a quart of *hydrogen* gas unites with a quart of *chlorine* gas, there is produced *one*, not *two*, quart of *hydrochloric acid gas.* This would at first appear to be contradictory to the impenetrability of matter, but it is explained by what we have already said of the porosity of matter. (See 1, above.)

(5.) *Matter is divisible—i.e.*, a portion of matter can be broken up into parts which retain the characteristic properties of the whole. We see frequent cases of this; perhaps the most striking is that of a grain of musk, which will scent a room for years and yet lose nothing appreciable of its weight. In this case the extreme minuteness of the tiny particles of the musk is beyond the power of imagination to conceive.

(6.) Matter at rest will remain at rest, unless acted upon by some new force tending to set it in motion; also, matter moving in a certain direc-

tion with a certain velocity, will continue to move in the same direction, and with the same velocity, unless it is acted upon by some new force, tending either to increase or diminish its velocity, or to propel it in the same or a different direction. This property of matter is called its *Inertia.*

To this we may add that

(7.) *Matter is indestructible.*—This is called the *Conservation of Matter*, and of it we shall proceed to treat more in detail.

CHAPTER IV.

THE CONSERVATION OF MATTER (INVOLVING AN ACCOUNT OF THE PHENOMENA OF COMBUSTION, AND OF SOME OF THE PROPERTIES OF MATTER AND OF THEIR ADAPTATIONS IN THE CONSTRUCTION OF INSTRUMENTS).

24. The Conservation of Matter. To an uninstructed person the question, "*Whether or no can matter be destroyed?*" would seem so easy to answer that the person asking it would appear to be trifling. Let us, however, pause awhile to consider whether this question is one quite so easy to answer as it at first appears to be.

When a candle burns it certainly seems that matter is destroyed, yet when we come closely to reason about it we are sadly puzzled to understand how that can actually be. The question which bothers us is this, "*If here was a candle one hour ago, where is that candle now?*" The confident person, who replies, "*Oh! it is destroyed!*" gives an answer with which people had long to be content. But the more we think about it, the more difficult we find it to be to understand what is the exact signification of the word "*destroyed.*" Then, to overcome this difficulty, the word *annihilation* was invented, which signifies "*brought to nothing;*" but this did not really help to solve the difficulty, for it then became necessary to show how *something* could be *brought to nothing.* If I am rich my riches can be brought to nothing, *so far as I am concerned*, by taking them from me, but still my goods exist somewhere; true they have been taken from me, yet equally truly they have gone to some one else. Thus the attempted solution of the difficulty only continued to land inquirers in another equally awkward. But I fancy I hear now a confident and impulsive reader remark, "*Wait a moment, the difficulty is not so great after all; suppose your wealth, like Antonio's, to consist of ships with cargoes; if those ships be burned at sea, then your wealth has been literally brought to nothing.*" To which comes the obvious reply that that simply brings us back to where we were before, for what we want to know is, "*How can something be brought to nothing? Truly the ships have disappeared, but to where are they gone? for every attempt to understand their disappearance from one place, except by their removal to other places, involves us in a perpetual round of difficulties.*"

Arguing in this way, men had long learned to doubt the possibility of

matter being really brought to nothing, *annihilated;* and at last chemistry came in to confirm and settle this doubt by showing that in many cases the *apparent* destruction of matter is certainly only its conversion into new states. For example, when a candle burns, its solid parts, being exposed to the heat of the flame, are first melted into the liquid state and then further converted into the gaseous condition. Of the gaseous elements to which the substance of the candle has now been reduced, the chief one consists of two gases called *hydrogen* and *carbon;* hence a candle is sometimes called a *hydro-carbon.* The preparation of *hydrogen* has been already shown (Fig. 33). If a light be put to a jar of it, and access of air be permitted to it, *it burns with a bluish flame*, and if the jar in which it has burned be examined after the gas has burned away, it will be found to be covered with tiny drops of water. This *water has been produced by the union of the hydrogen with some of the oxygen of the air.*

Carbon is but another name for *charcoal.* If a piece of charcoal be heated to redness and exposed to the air, it at once begins also to join itself to the oxygen of the air, and thus forms a new substance called *Carbonic Anhydride*, or, as it is more usually called, *Carbonic Acid Gas.*

The same things happen to the hydrogen and the carbon when a candle burns in air or in oxygen, that we have just described as happening to them separately. In each case the surrounding oxygen rushes towards the gases of the candle with intense eagerness, and those atoms of oxygen which first arrive there, having their choice of combining with the hydrogen or the carbon, prefer the former, and thus *water is formed;* the carbon meanwhile has been set free, and now exists uncombined in the form of very minute solid particles. But the heat produced by the union of oxygen and hydrogen is most intense; to this heat the carbon particles are now exposed and are thus rendered white hot; it is to the light shed by these glowing particles that the light of the candle is due. Presently, however, further supplies of oxygen flow in, and these, uniting with the heated carbon particles, give use to the formation of *carbonic anhydride.* The particles of the candle, then, have not been annihilated; they have simply gone to form new compounds, viz., *water* and *carbonic anhydride.* The same things occur when wood, or coal, or oil, or common gas, burns in air or in oxygen.

In Fig. 123 we have represented a candle burning, and we have shown the three cones or mantles of which its flame consists; viz., (1) an inner cone of unburnt gases; (2) a central luminous cone; (3) an outer dark cone. That the inner cone consists of unburnt gases may be shown by placing one end of a piece of bent glass tubing therein (see fig.) and applying a light to the other end, a flame is then produced which differs from the candle flame only in being smaller. That the central cone contains unburnt carbon may be shown by taking a clean white saucer and gradually lowering it upon the candle flame till it comes well into the middle cone;

if it be then removed and examined, it will be seen to be covered with a black deposit; this is carbon, and it has been deposited upon the saucer because this vessel was cold. Here, then, we get *black* carbon from a *white* candle.

It will thus be seen that there is no destruction of matter when a candle burns; what really takes place is, that the elements of which the candle is composed combine with the oxygen of the atmosphere and give rise to the new compounds *water* and *carbonic anhydride.*

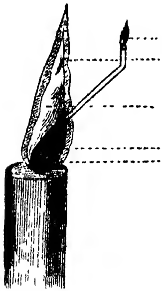


Fig. 123.

We have said above that the formation of the carbonic anhydride is delayed till after that of the water, because oxygen is not present in sufficient quantities to use up the hydrogen and the carbon at once. We have also stated that the luminosity of the candle is due to the presence of unburnt carbon in the state of minute solid particles. From this we may assume—

1st. That if it be possible by any means to supply oxygen in greater quantity to a burning candle, the combustion of the carbon and the hydrogen should both take place at the same time; and

2d. That, under these circumstances, as there will be no solid present in the flame, that flame will be non-luminous.

These two statements may be shown to be true thus:—

In Fig. 124 A′A is a small iron tube, the bottom part of which is cut into the form of a screw. In this part of it is an opening, B. This screw works into the tube C, and its aperture B may be thus brought to coincide with the other aperture, D. It is thus possible for air to enter at D, pass through B, and emerge again at A′. By giving the tube A′A a half turn inside C, it is also possible to close the aperture D and thus prevent the access of air.

While the aperture is closed the gas which flows out at A′ will burn with a luminous flame; but if the aperture be opened the flame will be a dark one, scarcely visible, but emitting intense heat. The explanation

is, that when air is allowed to enter and mingle with the coal gas, the combustion which takes place at A′ is complete and rapid; the carbon and the hydrogen being at once combined with the oxygen, there is no solid present in the flame, which is therefore non-luminous, but if some steel filings be dropped through the flame these at once become incandescent, and sparkle and dance in the flame like tiny stars.

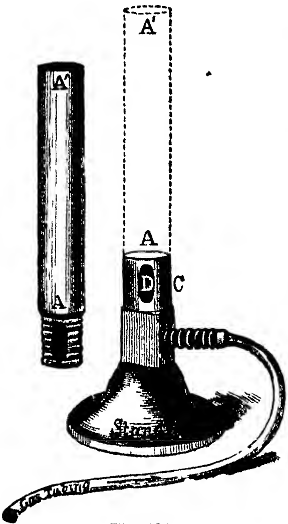


Fig. 124.

Such an instrument as that shown in Fig. 124 is called a *Bunsen's Burner*.

25. Animal Heat. If a little quicklime be dissolved in water and then allowed to stand quietly for some minutes, a clear liquid called *Lime Water* may be poured off. Now whenever *carbonic anhydride* comes into contact with clear *lime water*, the *lime water* is rendered milky in appearance. This effect is due to the production in the water of a great number of tiny particles of chalk: hence chalk is called a *Carbonate of Lime*, because it consists of a combination of lime and carbonic anhydride.

Now take a deep vessel, such as that represented in Fig. 82, and having put a lighted candle in it, place a piece of cardboard or an old book on the top of it, to prevent the escape of the gases which are produced by the combustion of the candle. After a while the light will go out, because all the oxygen which was in the vessel has been consumed. Now quickly, but not roughly, remove the candle, pour into the vessel a quantity of lime water and shake it up; it will become turbid (milky) thus proving that carbonic anhydride is produced by a burning candle. The same effect would be produced by burning wood or charcoal, or oil or gas, or any other hydro-carbon.


Fig. 125.

Now if a person take a piece of bent tubing and blow through it into a vessel of clear lime water (Fig. 125), it will be seen gradually to grow milky, from which it is clear that air breathed from our lungs contains carbonic anhydride.

Again, it has been stated that *water* is produced when a candle or other hydro-carbon burns in air or in pure oxygen; that such is the case may easily be shown by holding a tumbler or other cold glass vessel over one of these burning bodies; then the water, which is produced in the gaseous form, *i.e.*, as invisible steam, becomes condensed into tiny water-drops upon the cold inside of the tumbler. In the same way, if a person blow against a cold piece of glass, water-drops are formed and collect upon it. We can now understand why it is that the window-panes in churches, chapels, and lecture-rooms become covered with water-drops during meetings. Also, the curious figures which we find on our windows on frosty mornings we can now understand to be the watery vapour breathed out by the sleepers, which has been first condensed to water on the window-panes, and then frozen into the icy and fantastic figures that Jack Frost delights to trace.

When a piece of wood is exposed to heat gases are driven off from it and it gradually turns black, and is then called *Wood Charcoal.* Also, when a piece of meat is roasted too long, we find it turns black also and forms *Animal Charcoal.* Both these substances when burned give rise to carbonic anhydride. Seeing, then, that the body consists in great part of flesh, and that this flesh contains a great deal of carbon (*i.e.*, charcoal), it would seem natural to suppose that the carbonic anhydride which is exhaled by our lungs is produced by the combustion of the carbon of the body. This is really the truth of the matter, as we shall now proceed to show.

It has been already remarked that oxygen has a greater "*liking*" for hydrogen than for carbon. This "*liking*" of certain bodies in nature for others is called *Affinity.* Some bodies have this affinity in a very high degree and exert it towards a great number of bodies; others possess it, but in smaller degree, or only with regard to a very limited number of bodies. Oxygen is one of those substances whose affinity is both great and far extended, for it unites with almost every chemical element which has yet been discovered. Now if we could for a moment imagine each tiny atom of oxygen to be endowed with life and feeling, then we should see at a glance how these tiny lovers would eagerly fly to meet those other atoms of some other element, say carbon, for which oxygen has a great liking. But everybody knows that when two substances clash together heat is produced; consequently when a multitude of atoms of oxygen fly at a swift pace to meet a multitude of atoms of carbon, the effect of their encountering each other must be to develop heat; such heat is called the *Heat of Combustion.* In this way, then, the heat of a candle, of a gas light, and of burning fuel is produced. And in a similar manner is produced the heat of an animal's body, for the oxygen of the air, which is breathed into the lungs, penetrates into the blood vessels of the body, and there unites with certain particles of hydro-carbons which the

blood gathers up in its course through the body, and which are the waste products of the muscles (*i.e.*, the lean flesh) of the body; thus are formed both water and carbonic anhydride, and these two substances being carried to the lungs are there breathed out. In this way, also, that heat is produced which is so necessary to the maintenance of animal life.

From what we have now said the student will perceive the truth of what we have said on page 26, that the manner in which a candle burns is very similar to the burning of what has been aptly termed *the Lamp of Life* in man and other animals. It only remains to say that the circumstances under which a candle goes out are also those under which an animal dies. For example, as we have already stated, a candle goes out when immersed in the carbonic anhydride which is the product of its own combustion; in the same way an animal dies when surrounded by the carbonic anhydride produced by the functions of its own life.

26. Definition of Combustion. Because of the fact that oxygen is present in nearly every case of combustion with which we meet in our everyday life, this gas has been called *the Supporter of Combustion.* There are cases, however, in which combustion takes place without the presence of oxygen. Before going further, however, we had better state formally what we understand by *combustion.* Let it then be understood that, as used scientifically, *the term* COMBUSTION *signifies the act of combination of two or more chemical substances giving rise to heat and accompanied in most cases by the evolution of light.*

If we take a soda-water bottle filled with equal quantities of hydrogen and chlorine and apply a light to the mouth of it, these gases will unite with a loud explosion accompanied by heat and a distinct flash of light. Here is an instance of combustion in which oxygen is not concerned.

27. Combustion of the Diamond. The diamond is an exceedingly hard substance, and long defied all attempts made to burn it. Sir Isaac Newton, however, knowing its high refractive power for light, and noticing that such substances were usually compounds of carbon, predicted that if ever it was found possible to burn it, it would be found to be a carbon compound. Since then the diamond has been submitted to the heat of the electric arc, and when so treated it swells up into a black opaque mass of coke, thus proving the truth of Newton's prediction. Further, when heated to redness and then plunged into a jar of pure oxygen, it glows with white light like a star and produces carbonic anhydride. It is now certain that the diamond is the purest form of crystallised carbon yet known.

N.B.—Sugar also consists almost entirely of carbon and water; hence, if a thick syrup of sugar be made and then a sufficient quantity of sulphuric acid be added to it, this acid absorbs the water of the sugar

and thus separates it from the carbon, which now swells up in a black spongy mass. Sugar is thus one of the means by which carbon is supplied to the body for its nourishment.

28. The Expansion of Matter is the direct opposite of its compression; for if by the action of certain forces a quantity of matter can be caused to occupy a smaller volume, it is clear that the effect of forces acting in directions opposite to the former will be to cause that matter to expand and thus to fill a greater volume. We have already stated that heat acts generally as an expansive force, and of this we will now give some familiar instances.

(1.) *Heat causes SOLIDS to expand (and, therefore, cold causes them to contract).*

a. In constructing railways and laying down lines for tram-cars, care is taken to leave spaces between the ends of the rails. If this precaution were neglected the effect would be that in the heat of summer the rails having expanded would bulge out and the trains would be thrown off the rails.

b. Get a ring of iron or brass, or any other metal, just large enough to allow an iron or brass ball to drop through it when cold. Then heat this ball, and it will be found to have so increased in volume that it will not now pass through the ring. If weighed, however, it will be found to be no heavier when hot than it is when cold.

c Fig. 126 represents an apparatus of iron having a heated iron rod AB passed through holes in its upright portions. The end B has a hole

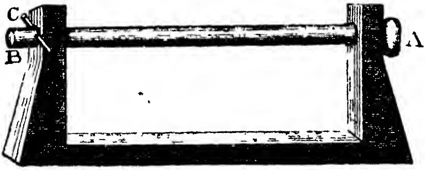


Fig. 126.

in it, through which is passed a small cast-iron rod C. The end A carries a nut, and while the rod is still hot this nut is screwed up close, and the rod is thus firmly fixed between the two upright portions of the apparatus. As the rod now cools it tends to contract, and this tendency becomes at last so great that the rod C is broken by the contracting force.

d. In Fig. 127 is represented a metal rod, the end of which is firmly secured in a pillar at A, while the other end rests against one end of an indicator BI. Beneath the rod is a brass trough, in which a quantity of

alcohol burns. As the rod AB gradually gets hotter under the influence of the burning alcohol, it expands, and as it cannot expand towards A, it

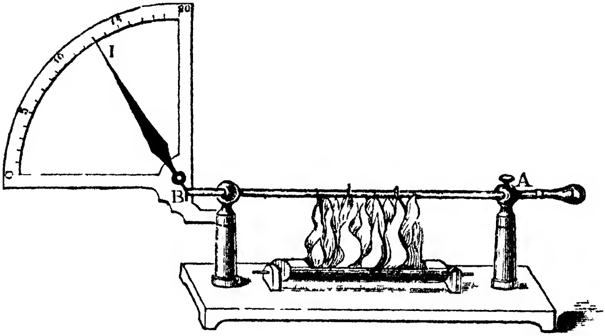


Fig. 127.

does so towards B, and in this way pushes the indicator round the graduated arc on which the end I points.

By taking the temperature of the rod before and after heating it, we are able to note the number of degrees through which the indicator travels to mark an increase of one centigrade degree in the heat of the rod. Thus by taking the rod AB of different metals, we are able to note for each the number of degrees on the graduated arc, which indicate an increase of one degree in the heat of each rod, and thus we can compare the effects produced in them by an equal increase of temperature.

Now if E represent the expansion produced in any rod of metal by an increase of one degree centigrade in its temperature, and R represent the length of that rod before expansion, then the fraction $\frac{E}{R}$ is called **the Coefficient of Expansion** for that metal.

e

We thus see that the *Coefficient of Linear Expansion* of any metal is a fraction which represents the ratio which exists between the amount of length gained by a rod of that metal while gaining one degree of temperature and its original length before expansion.

N.B.—Expansion, as will be seen presently, is not only *linear*, it is also *superficial* and *cubical*.

Fig. 128.

Let Fig. 128 represent a perfect cube, and let this cube be heated to one degree centigrade above its present temperature, and let *ab* be one foot long before expansion. Then if K represent *the linear expansion* (expressed as the fraction of a *foot*), it

is evident that $\frac{K}{1}$—*i.e.*, K—represents also *the coefficient of linear expansion.*

Therefore, since ab now $= 1 + K$, it is clear that bc also $= 1 + K$;

$$\therefore \text{ the area } abcd = (1 + K)(1 + K) = (1 + K)^2 = 1 + 2K + K^2,$$

but, *since K is a very small fraction*, K^2 is infinitely smaller; we may therefore neglect it, and say that the area *abcd*, which was originally 1 sq. ft., is now $(1 + 2K)$ sq. ft. In other words, it has gained $2K$ sq. ft.

Therefore, *the Coefficient of Superficial Expansion* is

$$\frac{2K}{1} = 2K;$$

i.e., twice the coefficient of linear expansion.

Again, if ab and bc have each gained K, it is evident that ce will also have gained the same, and therefore the cubic content of this solid, which originally was 1 cub. ft., will now be $(1 + K^3)$ cub. ft.; *i.e.*,

$$(1 + 3K + 3K^2 + K^3) \text{ cub. ft.}$$

But, as before, $3K^2$ and K^3 are such infinitely small numbers that we may neglect them. Thus we say that the volume 1 cub. ft. has expanded to become $(1 + 3K)$ cub. ft.; *i.e.*, it has gained $3K$ cub. ft.

Thus, then, *the Coefficient of Cubical Expansion* is

$$\frac{3K}{1} = 3K;$$

i.e., three times that of the linear expansion.

The coefficients of linear expansion of the following substances should be remembered by the student:—

Silver,	0·000019097	Iron (cast),	0·000011250
Gold,	0·000014660	Glass,	0·000008613
Platinum,	0·000008842	Brass,	0·000018782

It will be noticed that the coefficients for platinum and glass are very nearly the same; it thus becomes possible to fuse together these two substances, for their rates of expansion and contraction being thus practically the same, the glass does not crack when the cooling takes place. If their coefficients did differ in any appreciable degree, there would be a breaking of the glass, occasioned either by its being pulled inwards or being thrust outwards by the platinum.

e. **Breguet's Metallic Thermometer.**

As stated above, the coefficient of expansion of *brass* is considerably greater than that of *iron;* consequently if a strip of one of these metals be riveted to a strip of the other of the same length, and these be then heated, the combined strip becomes bent into a curve having *the iron on the inside.* On the contrary, if the compound strip be submitted to the

action of cold, the strip will become bent with *the brass on the inside.* In both cases, of course, the shorter of the two strips occupies the inside.

Advantage is taken of this in the construction of what is called *Breguet's Metallic Thermometer.*

In the list of coefficients given above it will be seen that gold occupies an intermediate position between silver and platinum, being less expansible than silver and more expansible than platinum—that is, under the influence of heat.

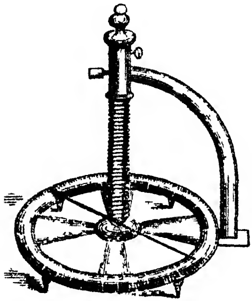


Fig. 129.

If, then, a strip of each of these metals be rolled out to a very thin "ribbon," and then an equal length of each of these be taken, fastened together, and coiled in a spiral form with the silver inside, the platinum outside, and the gold between them, and then be adjusted as in Fig. 129, with an index at the bottom, we shall have an instrument by means of which changes of temperature will be indicated; for an increase of temperature will serve to uncoil the spiral, while a decrease will serve to coil it more closely, and as the spiral winds or unwinds itself it moves the index over the graduated circle beneath it. Such an instrument is known as *Breguet's Metallic Thermometer.*

f. **The Gridiron Pendulum.**

When the pendulum of a clock is made longer it is found that it beats slower, and the clock *loses* time; and, *vice versâ,* when the pendulum is shortened the beats become quicker, and the clock *gains* time.

Therefore, in summer an ordinary clock will lose time because of the expansion of the pendulum rod, such expansion being due to the greater heat of summer over that of the average temperature. And, on the other hand, such a clock will gain time in winter because of the contraction of the pendulum rod.

It is easy to conceive that this is a great nuisance, and in order to remedy it several kinds of *compensation pendulums* have been invented, one of which is known as *Harrison's Gridiron Pendulum,* which we will now describe.

In Fig. 130, which is the plan of a Gridiron Pendulum, the rods marked S are all of steel, those marked B are all of brass; the length of the pendulum is measured from P to the centre of the bob C. When the atmospheric temperature rises all these rods expand, and it will be seen that whereas the elongation of the *steel* rods tends to lower the position

of the point p', that of the *brass* rods tends to raise it. But as the coefficient of expansion of brass is greater than that of steel, it is possible to choose these rods of such lengths that the expansion of the steel shall be counteracted by that of the brass, and thus to keep the length PC a constant quantity. The clock is thus prevented from losing time. When the temperature falls, the *contractions* similarly are equal; and thus the clock is prevented from gaining time.

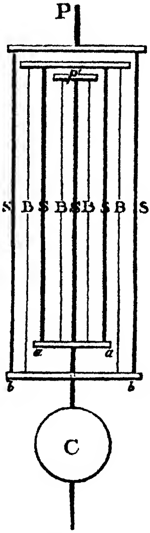


Fig. 130.

N.B.—It should be added that the rod p'C passes through the two cross bars *aa* and *bb*.

(2.) *Heat causes LIQUIDS to expand* (*and therefore cold causes them to contract*).

In Fig. 131 is represented a flask, in the mouth of which a cork is inserted. Through this cork a long glass tube is fitted; both tube and cork must fit very closely indeed. Let the whole be filled with water at an ordinary temperature. Then if the flask be heated (by being held between the hands, or by being plunged into warm water, or by means of a spirit lamp), the level of the liquid at *a* will first *sink*. This is because the heat first causes the glass of the flask to expand, and thus increases the volume of the flask. Soon, however, the heat reaches the water in the flask, which water then expands; and as a consequence the level *a* again rises, and that to a point much higher than the one at which it originally stood. If the heat be supplied by a lamp and be long continued, the generation of steam will begin, and then the experiment will be dangerous, because of the narrowness of the tube which forms its outlet; most likely the cork and the tube will fly out with an explosion.

If, instead of heating the apparatus, we had placed it in a freezing mixture, the level *a* would have descended steadily till the temperature of the liquid in the flask was at 4° C. It would then be found to rise again gradually till 0° C. was reached, *i.e.*, till *freezing* began to take place; at this point *a sudden and considerable expansion would take place.* Here is a case, then, in which *a body expands when cooling;* which is, of course, contrary to what usually occurs. The cause of it is supposed to be that the particles of the water re-arrange themselves just at this moment in such a manner as to leave unusually large spaces between them. That a re-arrangement does take place is easily shown by means of the electric lamp, but we have not space to describe it here.

Water is the principal, but not the only, body which expands in the act of solidification. Cast iron, bismuth, and antimony also expand

when solidifying; and we thus see that the law that matter expands under the influence of increased temperature is not a fundamental one, for it is true only in particular cases, though those cases are so numerous as to be well-nigh universal. Not so with the law of the *Conservation of Matter;* to that law there is no exception, nor does it appear that in the nature of things there *can* be any exception to it. Matter may be solid, or liquid, or gaseous; it may consist of *simple elements,* as oxygen, or *mixed elements,* as atmospheric air, or *compound substances,* as water; it may be firm and solid, as it is in iron or stone; it may be yielding and soft, as in clay or mud; it may be heavy, as gold, and it may be light, as hydrogen; it may be black, as coal, and it may be white, as chalk; it may be opaque, as the solid rock, and it may be transparent and invisible, as steam and oxygen and hydrogen; it may, and in fact does, undergo a thousand transformations, but is yet never lost to nature; an atom thereof is never destroyed, whether it be an atom of the inanimate dust, or of the more highly organised plant, or the fully developed animal, as in man; transmuted, dissipated through space it may be, but lost, apparently, it never can be.

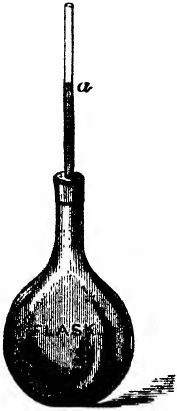


Fig. 131.

Whenever there is such an accumulation of coincidences as to enable us to establish an *almost* universal law, there is, of course, a principle in nature by which these coincidences can be explained. In the case before us, the explanation is that bodies in the act of solidifying re-arrange their particles (*i.e.*, they crystallise), and they usually so re-arrange them as to occupy less space than they did in the liquid state; but in some few cases the re-arranged particles require more room than they did before solidification. It is interesting to notice that in many cases this departure of Nature from an almost universal course of proceeding is of inestimable benefit to man, though sometimes this benefit is not unaccompanied by inconveniences. Such is the case with water, for since water expands in freezing, it follows that a pound of ice has a greater volume than a pound of cold water; in other words, *ice is lighter, volume for volume, than cold water,* therefore ice floats on cold water (Fig. 9). Now ice is a remarkably bad conductor of heat, therefore when once a sheet of ice has formed upon the surface of a body of water, it forms a shield from the cold to the water below it, for it prevents the rapid radiation of heat from that water. If ice were heavier than water it would sink as soon as it was formed, and the consequence would be that the whole body of the water, being exposed to the cold air above

and the ice below, would soon be frozen; and this freezing would proceed upwards, for each sheet of ice would sink as soon as it formed. The consequence would be a total destruction of all the fish, and probably of all the plants, that now live in water.

It has been already stated that 4° C. is the exact temperature at which water ceases to contract in bulk; this temperature is therefore called the **Point of the Maximum Density of Water**—*i.e.*, the *point at which any given volume of water is heaviest.* That this point is so near *the freezing-point* (*i.e.*, 0° C.) is a further benefit to mankind, for till the whole of a body of water has been reduced to this temperature no freezing at all can take place. As soon as the uppermost layer of water attains this temperature it at once sinks, because it is then heavier than at any other time; and thus before any freezing at all occurs, all the water from the lowest depths must have been brought to the surface and reduced to that low degree of temperature. Had 8° C. been the point of maximum density of water, the congelation of its surface would have become possible as soon as the lower layers had fallen to 8° C., instead of to 4° C.; in other words, the congelation of water would have set in sooner.

The expansion of water in freezing has been shown to be of benefit to man, in tending to preserve for him the fish and water-plants he desires to keep; it is also of some slight inconvenience to him, because of the bursting of his water-pipes in frosty weather. This is due to the action of the water as it expands into ice. Of course the mischief is not perceived when it is done; it is not till the thaw comes that these "bursts" are perceived, because it is not till then that the ice in the pipes is re-converted into water.

(3.) That *Heat causes GASES also to expand* has been already shown (Fig. 21); it only remains for us to mention here an exception to the ordinary rule for the expansion of gases.

It is found by experiment that when almost any gas is made 1° C. hotter, it gains $\frac{1}{273}$ of its former volume; therefore $\frac{1}{273}$ (or ·00366) is the coefficient of expansion of gases. It is to be carefully noted that this coefficient is the same for nearly all gases; and the reason apparently is that whereas in solids and liquids any additional heat which may be supplied to a body occupies itself partly in overcoming its attractive forces and partly in increasing the actual distances between its particles, in true gases it has only the latter of these functions to perform.

Let the following table of coefficients of *Gases* be carefully examined:—

Hydrogen,	0·00366
Air,	0·00367
Carbonic Anhydride,	0·00371
Sulphurous Anhydride,	0·00390

and it will be noted that the first two of these gases have the ordinary coefficient of expansion, but the last two have higher coefficients. Now we see from the following table of coefficients of expansion of *Liquids*, that that of

Water is	0·0466
Alcohol ,, ...	0·116
Mercury ,, ...	0·01543

So that this coefficient is greater for liquids than for gases.

It has therefore been considered—

1st. That the reason why the coefficients of *carbonic anhydride* and *sulphurous anhydride* are greater than those of hydrogen and most other gases or gaseous mixtures, is that the former are not pure gases, but are rather gaseous compounds, and are by nature inclined rather to the liquid than to the purely gaseous form. As we have already stated, *carbonic anhydride* is a compound of carbon and oxygen; *sulphurous anhydride* is similarly a compound of sulphur and oxygen, being formed when sulphur burns in air or in oxygen.

Whenever, then, we see a piece of carbon burning with its bright clear light in a jar of oxygen, or burning with less brilliancy in common atmospheric air, and whenever we see a piece of sulphur (brimstone) burning with its beautiful pale blue light, there is a consumption of solid matter going on, but the destruction of that matter is only *apparent*, it is not *real*. The particles of the carbon or the sulphur are but gone to form a new and invisible compound gas, and the compound nature thereof cannot altogether be hidden from observation, but is seen and noticed by scientific eyes trained to observe its symptoms, of which symptoms we have already shown that one is the greater numerical value of its coefficient of expansion.

2d. That gases may, therefore, be roughly divided into two classes; of which one class embraces those bodies whose coefficients of expansion are 0·00366 or thereabout, and the other class includes all those bodies whose coefficients differ considerably from 0 00366. The first class are most purely elementary bodies, and are sometimes called *Real Gases;* the others are generally compound bodies, and include what are usually called *Vapours*.

CHAPTER V.

THERMOMETERS: THEIR PRINCIPLES, CONSTRUCTION, AND USES.

29. The student is now in a position to realise the necessity for these useful instruments, and also the manner of their construction.

A Thermometer is an instrument for measuring the temperatures of bodies. When a body is hot, we say it has a *high* temperature; when it is cold, we say it has a *low* temperature. Consequently, when a body is becoming hotter, we say that its *temperature is rising;* when it is becoming cooler, we say that its *temperature is falling.*

Now seeing that solids, liquids, and gases all expand under the influence of heat, and contract when cooled, it might be thought that thermometers could easily be constructed of a solid, a liquid, or a gas, just as we chose. But in practice it is found that the expansions of a solid are too small to be easily noted, while those of a gas are too great and are influenced by the pressure of the atmosphere. *Liquids are therefore usually employed in the construction of thermometers.*

But all liquids are not equally suitable for this purpose, as the student will be able to gather from the following reasons which are given for the adoption of mercury (quicksilver). Mercury is preferred because—

1st. It rapidly assumes the temperature of bodies with which it is brought into contact.

2d. It expands regularly as its temperature increases.

3d. It is opaque, and is therefore easily seen in small tubes.

4th. It does not *wet* the glass containing it.

5th. It does not readily become gaseous or solid, for its boiling-point is higher than that of lead, and it never freezes in Western or Central Europe.

N.B.—In making scientific experiments *alcohol* thermometers are much used, because alcohol remains liquid at those very low temperatures at which mercury freezes.

A thermometer usually consists of a thin glass tube at one end of which a bulb has been blown. This bulb and the greater portion of the tube is filled with mercury (or alcohol, as the case may be). The upper portion of the tube is a vacuum. (See Fig. 132.)

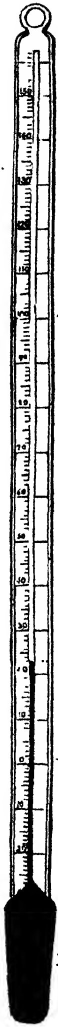


Fig. 132.

Let the level of the mercury at any moment stand at A; then, if the temperature rise, the mercury will expand and rise above A in the tube; if the temperature fall, the mercury will contract and fall below A in the tube.

That this instrument may be fit for indicating the temperature at any moment it is necessary to graduate it, *i.e.*, to divide its stem into steps (called *degrees*), and to number these according to an established system; so that, all thermometers being numbered alike, the same temperature may be in every case indicated by the same number of degrees of the thermometer.

In order to perform this graduation it is necessary to choose two invariable temperatures; these having been marked on the thermometer, the distance between them is then divided into an equal number of spaces, called *degrees;* and these having been numbered, the graduation is then so far complete.

(i.) **The Centigrade Thermometer.**

We will illustrate these remarks by describing the graduation of the centigrade thermometer shown in Fig. 132. At the same time, we recommend the student to obtain one of these instruments and examine it by aid of what here follows.

The point F.P. is the first of the fixed invariable points selected in graduating this thermometer; it is *the freezing-point of water*, or, which is the same thing, it is *the melting-point of ice*. In order to find this point the instrument is plunged into a vessel containing pounded ice in the act of melting, and as soon as the mercury ceases to sink in the tube, the point F.P. (*freezing-point*), at which it then stands, is marked on the thermometer.

The point B.P. is the second of the fixed invariable points selected; it is *the boiling-point of water*. In order to find this point the instrument is placed in the steam of boiling water, for such steam has the same temperature as the boiling water. As soon as the mercury becomes stationary the point B.P. (*boiling-point*) is marked on the instrument.

These two points having been found, the first of them is marked 0° (*Zero*), and the second is marked 100°. The distance between them is divided into 100 *grades* or *steps* (called *degrees*); this graduation is continued above the 100° and below *the Zero*, and the instrument is complete. Such an instrument as this is called *a Centigrade Ther-*

mometer, because there are *one hundred grades* (or steps) between its freezing and its boiling points.

It is also sometimes called *the Celsius Thermometer*, because it was first made by a Frenchman named Celsius. This is the thermometer most in use among men of science; there are two others also in use, and these we will now shortly describe.

(ii.) **Réaumur's Thermometer.** This differs from the Centigrade thermometer in the number affixed to its boiling-point. Réaumur chose to call it 80°; while, as we have already shown, Celsius called his 100°. They both called the freezing-point of water 0°.

(iii.) **The Fahrenheit Thermometer** takes 212° as its boiling-point, 32° as its freezing-point, and its zero is therefore 32° below its freezing-point. This thermometer receives its name from its constructor *Fahrenheit.* At the time of its adoption it was supposed that the cold produced by mixing together equal weights of *sal ammoniac* (*ammonic chloride*) and snow was the utmost cold that could be obtained; the temperature produced by such a mixture was therefore selected for the zero of Fahrenheit's thermometer.

30. Conversion of the Readings of one of these Thermometers into Readings of the others.

As we have already stated, the Centigrade thermometer is the one in most general use; in England, in Holland, and in North America, how-

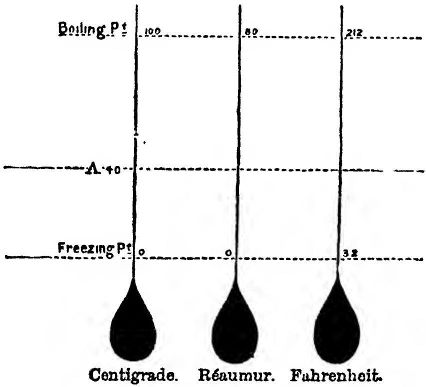


Fig. 133.

ever, Fahrenheit's is still much in use; in Germany Réaumur's is used. It becomes necessary, therefore, to show how the reading of one of these thermometers may be expressed as a reading on either of the others.

Let Fig. 133 represent three thermometers exactly alike, but graduated according to the three different systems, and let it be required to find what the readings corresponding to 40° C. will be on the Réaumur and Fahrenheit thermometers respectively.

From the figure we find that the distances between the freezing and the boiling points are the same in all three thermometers, but that this distance is divided into 100 steps in the Centigrade, 80 in the Réaumur, and 180 in the Fahrenheit thermometer; so that we get—

100 *steps Centigrade* = 80 *steps Réaumur* = 180 *steps Fahrenheit*,

which may be more conveniently written thus—

$$100 \textit{ steps C.} = 80 \textit{ steps R.} = 180 \textit{ steps F.};$$

therefore, dividing by 100, we get—

$$1 \textit{ step C.} = \frac{4}{5} \textit{ step R.} = \frac{9}{5} \textit{ step F.};$$

therefore, multiplying by 40, we get—

$$40 \textit{ steps C.} = \frac{40 \times 4}{5} \textit{ steps R.} = \frac{40 \times 9}{5} \textit{ steps F.};$$

$$= 32 \textit{ steps R.} = 72 \textit{ steps F.}$$

But (i.) in the *Réaumur* thermometer the numbering of the steps begins at the same temperature as in the Centigrade; therefore, the 32d step from the freezing-point will be called *number* 32, *i.e.*, 32°

$$\therefore 40° \text{ C.} = 32° \text{ R.}$$

(ii.) In the Fahrenheit thermometer, however, the numbering of the steps begins 32 steps sooner than in the Centigrade; therefore, in Fahrenheit's thermometer, the 72d step above the freezing-point is called number (32 + 72, *i.e*) 104

$$\therefore 40° \text{ C.} = 104° \text{ F.}$$

N.B.—In converting these thermometric readings, the student must carefully remark that the expression

$$40° \text{ C.} = 32° \text{ R.} = 104° \text{ F.}$$

does *not* signify that 40 steps on the Centigrade thermometer equals 32 steps on the Réaumur or 104 steps on the Fahrenheit; what it really means is that that step which on the Centigrade thermometer is numbered 40 would on a Réaumur be numbered 32, and on a Fahrenheit 104. As we have shown above,

$$40 \textit{ steps C.} = 32 \textit{ steps R.} = 72 \textit{ steps F.};$$

so that if the temperature of a body increase 40° as measured on the Centigrade thermometer, it would increase 32° as measured on the Réaumur, and 72° as measured on the Fahrenheit.

General Formulæ.

If C, R, and F represent the readings on a Centigrade, a Réaumur, and a Fahrenheit thermometer, which represent any given temperature, then—

$$\begin{cases} \text{(i.) } C = \frac{5}{4} R. \\ \text{(ii.) } C = \frac{5}{9} \left[F - 32\right] \end{cases}$$

$$\begin{cases} \text{(iii.) } R = \frac{4}{5} C. \\ \text{(iv.) } R = \frac{4}{9} \left[F - 32\right] \end{cases}$$

$$\begin{cases} \text{(v.) } F = \frac{9}{5} C + 32. \\ \text{(vi.) } F = \frac{9}{4} R + 32. \end{cases}$$

31. Precautions necessary in Constructing a Thermometer.

(1.) In determining the freezing-point, the pounded ice or snow in which the instrument is immersed must be carefully and cautiously stirred, in order to keep it all at one temperature.

(2.) In determining the boiling-point, the following precautions are necessary:—

a. The ebullition—*i.e.*, boiling—in F (Fig. 134) must be kept up briskly.

b. The indraught of currents of air into F must be prevented; this is effected by cotton-wool placed lightly in the mouth of the flask at C.

c. The heating of the upper portions of the flask, F, by radiation from the burner must be prevented. This is done by placing F on a metal plate, P, which has a hole in the centre; through this hole the bottom of the flask just passes. As this flask becomes hot it begins to radiate its heat; therefore to prevent any of this heat reaching F, a quantity of sand is placed on P. (See S, Fig. 134.)

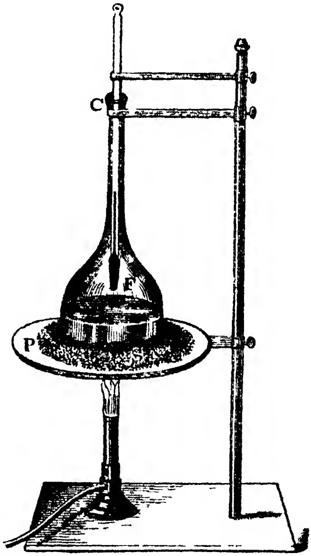


Fig. 134.

d. As the boiling-point of every liquid is influenced by atmospheric pressure (§ 7), the boiling-point, when found, has to be corrected, to bring it to the universal pre-determined pressure of 760 mm.

CHAPTER VI.

ENERGY: ITS CONSERVATION, SOURCES, AND EFFECTS.

32. **Its Conservation.** The reader who has carefully followed us through our Chapter IV., and has there understood what is meant by the *Conservation of Matter*, will now be ready to make a step further, and confront the more difficult proposition involved in the *Conservation of Energy*.

By *Energy* we mean *the power to do work;* therefore, by the *Conservation of Energy* we mean that the power to do work which now exists in the universe is exactly equal to the power to do work which has existed in times gone by and which will exist in future times. Therefore energy, like matter, is perfectly indestructible and perfectly uncreatable.

If I lift a 20 lb. weight to a height of ten feet from the ground, a portion of my *vital energy* will be consumed in the act; I shall be weaker than I was before the act. But will the stone now possess the energy I have lost? Certainly; for if, in its raised position, this weight be attached to one end of a cord passing over a perfect pulley, it will, with the slightest downward push, fall towards the earth with sufficient force to raise another body of equal weight to a height equal to that from which it has itself now fallen. The force with which such a weight falls is called *vis viva—i.e.*, force which is producing motion. Here, then, we have an instance of a change of *vital energy* into *vis viva;* and we thus learn that energy undergoes modifications. Still, however, the actual amount of energy has neither been increased nor diminished; a weight of 20 lb. falling through 10 ft. raised another weight of 20 lb. also through 10 ft.

Again, if the same force which was employed to raise the weight be now employed to rub two bodies together, it will be found that the heat developed by the friction of these bodies has the same work-producing power as the vital energy consumed to produce it. Hence we learn that *heat is produced by friction, that heat is another form of energy, and that in every particular case it is equal in working power to the energy consumed in producing it,* so that when vital force converts to heat there is neither loss nor gain of actual energy.

Again, if vital force be employed to rub the back of a cat, heat and electricity will be developed; and the combined working power of this heat and electricity will be equal to that of the force consumed in producing them. Here we see, then, that vital force can be changed to electricity; we have already seen that it can be converted to *vis viva* and to heat.

Again, if a lucifer match be rubbed against a rough body the friction produces heat, and this heat ignites the phosphorus of the match; and now a greater quantity of heat is produced than is equivalent to the vital energy consumed in striking the match. Here we might too hastily jump to the conclusion that heat can sometimes be created. But such is not the case; the fact is, that in phosphorus there is another force stored up, this force we have already met with (p. 119) as *Chemical Force*, or *Chemical Affinity*. By reason of this force, which although hidden is nevertheless eternally striving to produce its own peculiar effects, the phosphorus contained in the match unceasingly strives to rush towards any oxygen near it. Its anxiety to do this, so to speak, is so great that pure phosphorus exposed to air is, in the absence of preventing causes, able to ignite itself and to burn. In so doing its particles rush to join with those of the oxygen, and thus we get an example of chemical affinity converting into *vis viva* and then into the heat of combustion. Before it is struck there are, in a match, forces at work preventing this union of the phosphorus and the oxygen; these opposing forces are due to the presence of other bodies in the match besides the phosphorus. But when the match is struck heat is produced, and this heat, acting as the friend and ally of the chemical affinity of phosphorus for oxygen, counteracts the opposing forces of the other bodies present, and starts the combustion. Once started, the heat due to the combustion (for *combustion is always accompanied by the evolution of heat*) keeps the action from dying out till either the whole of the phosphorus or the whole of the oxygen is consumed. Thus we learn that *a given amount of one form of energy, in this case heat, although it cannot create energy greater in quantity than itself, can yet set free large quantities of other latent energy, and thus indirectly produce results wholly incommensurate with its own work-producing power.*

Again, let us trace the changes which may take place when a gun is fired.

The *vital force* of man raises the hammer; the hammer, when released and set free to fall, does so with *vis viva;* this *vis viva* changes to *heat* as soon as the hammer strikes the nipple of the gun; this heat enables the *chemical forces* stored up in the gunpowder to set to work. The consequence is, that the different material elements of the gunpowder rush towards each other with great rapidity, and thus their chemical force changes to *vis viva;* as soon as they strike together this *vis viva* converts

to *heat;* by reason of this heat the solid material of the gunpowder changes to highly-heated gases (§ 3), and these gases expanding with the great energy due to their heated condition, drive out the bullet with great speed. Thus again heat is converted to *vis viva.* As soon as the bullet strikes the target a sound is produced, and the bullet becomes melted by reason of the heat produced by its impact. Thus *vis viva* converts to *sound* and *heat.* These forces spread themselves, by radiation chiefly, through the atmosphere; by degrees the sound also converts to heat (p. 51), and the whole heat goes to promote the growth of plants and animals, and once more to produce in plants those stored-up *chemical forces* which give rise to combustion. These plants will go to nourish men and to produce in them that *vital energy* which first raised the hammer; with this vital energy the man may now rub the back of a cat and develop *electricity.*

Here, then, we may see that *force,* or *energy,* may undergo a whole cycle of changes and return to its original form at last; that while undergoing these changes it may liberate—*though it cannot create*—other latent energies, as when heat promotes combustion; and that *there is no known force into which every other kind of force may not convert.* We may here repeat that this energy, though it may be to all practical intents and purposes consumed, is yet not destroyed; it exists still, and exerts an eternal influence tending still to produce the effects peculiar to it in its several manifestations.

It would follow from this that a body once in motion would ever continue in motion unless its progress was forcibly arrested. Such is the case. The heavenly bodies moving unceasingly in their orbits are instances of it. This is, indeed, an illustration of what is called the *Law of Inertia,* which law is, that *a body moving in a given direction with a given velocity, will continue to move in that direction and with that velocity till its progress is diverted or arrested by the action of a new and opposing force.*

33. Its Sources. The study of the origin of *Force* or *Energy* is so closely bound up with that of the origin of our universe that we cannot here go deeply into it. We must, however, explain that the whole of our planetary system, including the Earth, the Sun, the Moon, Jupiter, Saturn, Mars, Venus, and all the myriads of other heavenly bodies known to us, were probably at one time a much more extensive but vastly less dense mass of finely divided matter, so fine, indeed, that millions of cubic miles of it would not weigh a grain. This vast body of matter probably revolved (as the earth now does) on an axis. In process of long ages portions of this matter became more condensed and formed nuclei, and round these nuclei the greater part of the remaining gaseous matters gradually collected and condensed, till sun, moon, earth, and

other bodies were at last formed. All this while, however, these bodies of matter maintained their original manner of revolution, not now on one common axis, but each on its own peculiar axis. In this way we account for the revolution of the inferior bodies round the sun as a centre, and that all of them follow the same direction in their orbits round the sun.

Although we derive some extremely small amount of our heat from the interior of the earth, our great supply of energy is derived from the sun; this energy reaches us in the form of Light, Heat, and Chemical Force, as we will now proceed to show.

1st. **Light.** Let a ray of sunlight, S (Fig. 135), be allowed to pass through the aperture A and impinge upon a prism at P. Such a ray will then be refracted towards the base of the prism (p. 102); but it will be found that if a screen be placed to receive this refracted ray there will be produced on it NOT one spot of white light, but a band of colours as of a rainbow; and whatever be the position of the prism the colours will

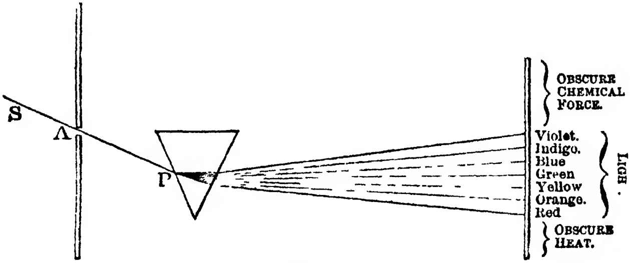


Fig 135.

always be found so arranged on the screen that the position of the red corresponds to the apex of the prism and the violet to its base, and the whole series of colours is arranged in the order shown in the figure, viz., Red, Orange, Yellow, Green, Blue, Indigo, Violet. This appearance is called THE SOLAR SPECTRUM. In this way we learn that the *white light of the sun is a compound of lights of the seven colours abovementioned,* which colours are therefore called the SEVEN PRISMATIC COLOURS.

The explanation of the action of the prism in this case is that the energy which produces the red rays of the spectrum differs in amount from that producing the violet rays, that between the red rays and the violet there are other rays whose energies all differ from each other and from those of the red and the violet; that the nearer any one colour is to any other colour in the spectrum the more nearly their energies coincide in amount, and that the result of these differences in energy is differences in refrangibility of the rays produced, the red rays being the least

refrangible, the violet the most refrangible, and the intermediate rays being more or less refrangible according as they are situated nearer to or farther from the violet in the spectrum.

If a prism corresponding to the one shown in Fig. 135 be placed between that prism and the screen shown in the figure, but in an inverted position, and be so placed as to intercept all the rays which have passed through the first prism, the prismatic colours will disappear from the screen and a single spot of white will appear there. This is, of course, due to the recomposition of the white light out of its constituent colours. Thus we have learnt by analysis (*i.e.*, the pulling apart) of white light that it consists of the seven prismatic colours; we have confirmed this by synthesis (*i.e.*, by the recomposing white light out of these elements). This we may also effect in another manner, for if we take a disc of cardboard and divide it into seven equal sections, and on these paint the seven prismatic colours in their proper order, and then cause the disc to revolve rapidly, we shall see on the disc not each separate colour, but (practically) the whole seven together, and then the cardboard will appear white, or rather grey.

All this is very interesting and very instructive also. We now understand what *colour* really is. It is not a substance which resides in bodies, it is an effect produced upon us by the sun's energy, when that energy in the shape of light is reflected from bodies to our eyes, and thence is communicated to our brains.

But the reader will at once raise a difficulty. Light from the sun is colourless, we cannot see it as it darts through space; it is not till in its rapid progress it lights up some portion of matter that it becomes seeable, and, of course, then only by its effects. Light is energy only, and, therefore, cannot itself be seen. How is it, then, the reader will ask, that at any one moment the sun's light may make one object appear white, another black, another red, another green, &c. Let us try to explain this.

If ALL the solar light which falls on a body be reflected unaltered from that body, the body will of course appear *white;* if NONE of it be reflected the body will appear *black;* if only the RED be reflected it will appear *red;* and so with the other colours, for different bodies possess different powers of acting on the sunlight incident upon them; some absorb practically no light at all; these are white: some absorb it all; these are black: some absorb one prismatic colour and reflect the remainder; these are coloured according to a combination of the colours reflected; others absorb all colours but one and this one they reflect; these are of the colour they reflect.

We have thus learnt that two or more energies can combine to produce an effect upon our perceptions which is like to one of the effects proper to these causes separately; as when the seven differing energies

which produce singly the seven prismatic colours unite to produce upon us the combined effect called white light.

N.B.—In consequence of the unequal refrangibility of the seven constituent elements of white light, it is found that in certain cases the images produced by lenses are tinged with coloured edges. This is known as *Chromatic Aberration.*

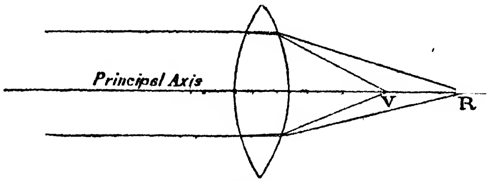


Fig. 136.

The reason of this is clear from Fig. 136, which shows the red rays as focussed at R, while the violet are focussed at V; this is in agreement with what we have already said, that the red are the least refrangible rays of the spectrum; of course the other rays are brought to foci situated between R and V.

2d. **Heat and Chemical Force.** Returning to Fig. 135, it can be shown by experiment that the rays of energy which produce the *Violet* of the spectrum have but little of the energy which produces heat; the same remark applies to the *Indigo*, *Blue*, and *Green*. The *Yellow* contains a little, the *Orange* a considerable quantity, and the *Red* a great quantity of heat-producing energy. But beyond the red is a dark region in which are heat rays of greater power than any in the luminous spectrum. Similarly, beyond the violet is another dark region containing active rays of *Chemical* Force. Chemical rays are also to be found in the luminous spectrum, and are more numerous in the region towards the blue than towards the red.

The leaves of plants look green because they absorb from the light the chemically active rays at the blue end, and the heating rays at the red end of the spectrum; for leaves act to plants as lungs do to animals, therefore in them the chemical processes consequent upon the nourishment and growth of the plant take place. For many of these processes supplies of heat are necessary (for although heat is always produced when chemical combinations take place, it is *not always* produced in quantities sufficient to enable these processes to continue without the aid of other heat), and these supplies also are obtained from the energy poured by the sun upon the plants. The red end and the blue end of the spectrum having thus been greatly weakened, the central green is left to give its tint to the leaves.

We have here seen the radiant energy of the sun transformed into the stored-up chemical energy of the chemical compounds which form plants, and we are thus led back again to the *Conservation of Energy;* for we can now better understand what we have before stated concerning the apparent, but apparent only, creation of energy which takes place when a small amount of heat sets free a large amount of energy stored up as latent chemical affinity (p. 119).

34. Its Effects. Although energy cannot be lost nor destroyed, we have already shown that it can be hidden; though even when hidden it is nevertheless active, and can only be kept from exhibiting itself (in the shape of the performance of work) by the opposing action of other energy equal to it. And it must not be forgotten that *the qualities of matter may, and often do, supply forces which tend to modify and even to nullify the great and more obvious energies of Nature.* For instance, the forces of cohesion and gravity continually oppose themselves to the repellant action of heat (see p. 7); and there are also other and more curious cases in which the properties of matter oppose or otherwise modify the action of such obvious forces as those which give rise to sound, light, and heat, as we will now proceed to show.

(1.) Energy, though distinct from matter, cannot yet be conceived as existing utterly independently of matter. As we have already said, *Colour* is no material substance at all, yet we cannot conceive colour except as an effect produced upon our minds by energy proceeding from some material body.

In like manner, we cannot conceive that any of the light and heat which pour out from the sun can be altogether lost by radiation into an absolutely empty space beyond the stars. If there be a limit to the space occupied by matter, it is utterly inconceivable that the energy we know as light and heat can radiate into it and be there lost. True it is that heat and light, in their propagation from point to point of space, are independent of the atmosphere, and apparently (*i.e.*, as far as our experiments as yet go) of any other material substance; but this does not prove that the transmission of these energies through an *absolute* vacuum is possible. Such a thing is, indeed, inconceivable.

Whether possible or no, however, there is no doubt that light or heat, travelling through space filled with matter, would, if it came to purely empty space, return into that space rather than pass into the vacuum before it. Thus light and heat are reflected back, not only from the surface of a body *denser* than that in which it has been proceeding, but also from one *less dense*, as in the case of the *Total Reflection* of light coming up from the depths of a body of water, already treated of (Fig. 107).

Whether energy, passing onward through one medium and coming

into contact with another medium (whatever the density of the new medium be), shall be propagated by it or reflected from it, depends upon the power of the particles of the new medium to take up the vibrations of the former one. And this power, though not independent of density altogether, is yet far from being altogether ruled by it.

Glass and *Marble* differ in their powers to take up and propagate the vibrations which produce light. The first possesses this power in a high degree, and is hence said to be *transparent;* the second scarcely possesses this power at all, and is therefore called *opaque.*

Some bodies, such as *Rock Salt* and *Fluorspar*, readily take up and transmit radiant heat, and are therefore called *diathermanous;* others, such as *Alum*, *Sugar-candy*, and *Ice*, have powers for transmitting radiant heat which are extremely feeble, they are therefore termed *athermanous.* Thus DIATHERMANCY *is to Radiant Heat just what* TRANSPARENCY *is to Light.*

Sound, also, though freely propagated by many solid bodies, is but feebly transmitted by sawdust and by felt.

Further, there are cases in which the same body conducts energy with different powers and different velocities in different directions. For example, sound is more freely conveyed in the direction of the "grain" of timber than at right angles to it. The same is true of heat. Light, also, travels more freely in the direction of the axis of a crystal than at right angles to it.

(2) Energy can accumulate in bodies and then produce effects which are startlingly great compared with their beginnings. Of course, in such cases there is, however, no creation of force; there is an accumulation of force, and that is all. Let us give two widely different examples of this.

a. If a musical box be encased in felt of a good thickness, its music will not be heard. If a long rod be passed through the felt and touch the box inside, while its other end is in the outer air, no sound will be heard, although this rod is actually producing vibrations which, if great enough, would excite in us the sense of music. But if this free end of the rod be placed in contact with a large flat board (or, better still, a large hollow box of resonous wood) freely suspended in the air, the music of the enclosed musical box will be plain enough to all listeners, for then the sound energy of the vibrating rod becomes communicated to, and stored up in, the board or sound-box at its end, and the vibrations of this larger body combine to produce others whose amplitudes are larger than those of the rod, and they thus produce a series of sounds loud enough to be audible. Here, then, we see energy depending for its effect upon the resonous quality of the matter of wood, a principle not forgotten by those who make fiddles.

b. **Resonance.** If a tuning-fork which produces a given note be caused

to approach a cylindrical jar of a proper depth, it will be found that the note becomes louder; pour now a quantity of water into the jar, and this increase in the sound does not take place. Not, indeed, with this tuning-fork, but with one whose fundamental note is somewhat higher. These effects are due to the action of the air enclosed in the cylinder. A column of air of a given depth will resound to a certain note and to no other, for reasons that we shall see immediately; at present we are concerned to remark that the effect of any given energy (*e.g.*, that producing a certain musical note) is dependent for some of its effects upon the qualities of the matter in which it comes in contact (as in this case, the accidental depth of a jar containing air).

However, that the depth of this column of air may be seen to be dependent upon law for its results, we will here consider this subject of *Resonance* a little more closely.

Careful experiments show that *the depth of the column of air which resounds to any given musical note is one-fourth of the length of the sound wave which produces that note.* With this law to help us we easily understand how the results called *Resonance* are produced.

Let us turn to Fig. 39; the length of the wave of the tuning-fork there represented is the distance between the condensation produced by the fork when passing the point B in its journey to B″, and the succeeding condensation produced by the fork when passing the same point when travelling in the same direction. Let this distance be represented by $4x$. Then—

(i.) While *the fork* passes from B to B″, the distance performed by *the wave* is represented by x.

(ii.) While *the fork* passes from B″ to B, the distance performed by *the wave* is represented by x.

(iii.) Therefore, while *the fork* passes from B to B″ *and back*, the distance performed by *the wave* is $2x$.

Now, let the tuning-fork of Fig. 39 be represented in Fig. 137 as sounding over a glass jar whose depth is x. Then the condensation produced by the fork when passing B on its way to B″ will return just in time to overtake the fork as it passes B on its return journey, *i.e.*, on its way to B′. Therefore, the air now on that side of B which lies towards B′ will be urged towards B′, not only by the tuning-fork, but also by the wave now as it were reflected from the bottom of the jar. Thus a new wave is produced whose period of vibration is equal to that of the tuning-fork, but the amplitude of whose vibration is much increased. And this effect is still further heightened the next time the fork passes over the same ground; the effect, at least, is that the column of the air enclosed in the jar comes to vibrate in unison with the fork, and thus produces that augmentation of the sound which is called *Resonance.*

And this effect is clearly dependent on the depth of the jar. If the

jar be a little too deep or a little too shallow, the wave reflected from it does not arrive at the moment proper for reinforcing and augmenting the action of the fork, and there is consequently no resonance.

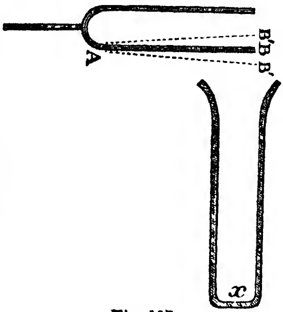


Fig. 137.

Now if such a wave pass through a tube open at both ends it will, after passing through the tube, be reflected from its open end, because there it meets with air which is free to expand, not being enclosed by the walls of a tube, as is that through which the wave has been passing. Let us now suppose the jar in Fig. 137 to be double its present length and open at both ends, and, then, let us further suppose the condensed portion of a wave from the fork to pass into this open pipe, and to be reflected from the end thereof; at the middle point of the tube this condensation will meet the rarefaction of the same wave, and the consequence will be that just at this point there will be no motion at all of the air particles; such a point is called a *node.* Passing the node this condensation will then travel to the mouth of the jar, and will arrive just in time to augment the condensation of the air produced by the fork in its journey from B to B′. It will thus act exactly as the stopped tube or jar acted in Fig. 137. We thus see that *the note to which a* CLOSED *tube of any given length resounds is in the same degree increased by resonance from an* OPEN *tube of double its length.*

The student must carefully bear in mind that there is in these cases no creation of energy, nor any real creation of effect. The effect *seems* to be augmented, but the fact really is that the vibrating energy of the fork, which would otherwise be dissipated in the atmosphere in the production of heat, is collected in the tubes; it there sets the columns of air in vibration, and these vibrations, being from the nature of the circumstances similar to those of the sound-producing body, go to augment its effects upon our organs of hearing. There is thus a cumulation of energy but no creation thereof; there is consequently a cumulation of effects but no creation thereof. The increase in the sound is the effect of the stored-up force of former vibrations.

We have already noticed that the higher a note is the shorter is its wave-length; it follows that the higher a note is the shallower is the tube which resounds to it. *If there be two tubes the depth of one of which is double that of the other, the note to which the shorter one resounds is the octave of the other.*

c. **Beats.** Let Fig. 138 represent what is called a **Monochord** or **Sono-**

meter. It consists usually of one string, AA (whence its name *Monochord*), stretched by a weight, W, across two little bridges, B, B′. These bridges, which are fixed, rest upon a box constructed of very thin re-

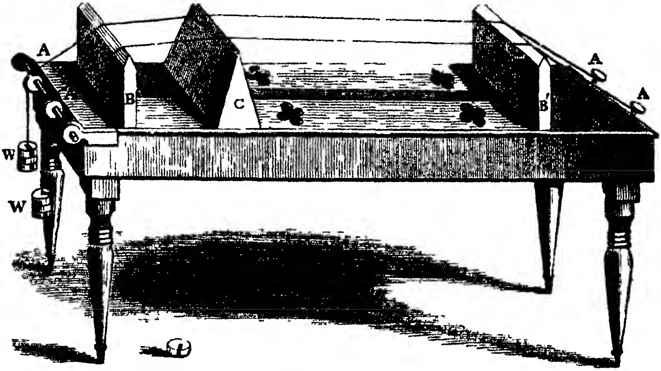


Fig 138.

sonous wood. This box is for strengthening the sound. A third bridge, C, is movable, and by means of it the length of string (or wire) which we desire to set in vibration can be increased or diminished as we please. The weight W can also be varied at will; and, of course, the string (or wire) can in like manner be removed and another substituted for it when we please.

By varying the length, the thickness, the density, and the stretching weight of the string (or wire) we find by experiment that, other things in each case remaining constant, *the number of vibrations per second varies*—

Firstly, *inversely as the length of the string;*

Secondly, *inversely as the radius of the thickness of the string;*

Thirdly, *directly as the square root of the stretching weight—i.e.*, "the tension;"

Fourthly, *inversely as the square root of the density of the string.*

Let us now suppose *two* strings (instead of one) whose vibrating portions are of equal lengths, diameters, and densities, to be stretched by equal weights across the same sound box; it is clear that these will both produce the same number of vibrations per second, and will therefore produce the same note.

Now, in order that they may both vibrate together, it is not necessary that we pluck both of them in order to set them vibrating; for if one of them vibrate, it will thereby cause little vibratory waves to pass from it in all directions, and some of these will impinge upon the neighbouring wire and cause it to execute vibrations of the same rapidity as their own, and

these, at first of a most tiny smallness, gradually increase in amplitude because of the oft and periodic recurrence upon the wire of the impulses due to the waves of its neighbour, and this action increases till the second string (or wire) swings with vibrations equal in rapidity and equal in amplitude to those of the string first set in motion. The two strings now vibrating together will produce waves whose condensations and rarefactions exactly coincide; these condensations consequently become more dense and the rarefactions more rare : the sound is consequently intensified.

If, however, the vibrations produced by these strings could be so arranged that the condensations of the waves of one corresponded with the rarefactions of the waves of the other, there would be no sound at all, for there would be no amplitude to the vibrations of the air through which these waves pass; in a word, there would be no vibrations, and consequently no sound. We thus see that *one sound may be destroyed by another;* and, reasoning similarly, it is clear that *light may destroy light, and heat may also be destroyed by heat.* We need scarcely remind our readers that in neither of these cases is energy actually *destroyed;* it is simply paralysed and nullified by one portion of it successfully opposing the action of another and equal portion.

The destruction of sound, by this interference of one series of waves with another, can be shown thus:—Let us, as above, take two strings which are vibrating in unison, and add a little to the stretching weight of one of them; they no longer vibrate together, but if we listen attentively we shall hear the two different notes produced by them, and at certain regular intervals we shall hear *beats*—that is, intervals when both sounds disappear for a moment and there is absolute silence. The reason is, that the waves produced by the one string are slightly shorter than those of the other string; and thus it by and by happens that the condensation of the one wave coincides exactly with the rarefaction of the other, and then the one series of waves destroys the other, and silence is the result.

To make this more clear, let us suppose the length of the waves of one series to be 26 inches, and of the other, 25 inches. Then, as each of these waves is produced in the same interval of time, it is clear that of the *first* pair of waves the one is an inch behind the other; of the *second* pair, the one is 2 inches behind the other; and of the *thirteenth* pair, the one is just 13 inches behind the other—that is, the condensation of the smaller wave is exactly in the rarefaction of the larger, hence silence ensues.

The *beats* in music can easily be produced by touching any two adjacent keys of a piano; the seventh and eighth of the octave serve the purpose as well as any.

Before leaving this subject of the vibration of strings, it will be well to describe an experiment by which the formation of *nodes* and *ventral segments* on a vibrating string may be shown.

We have already described the formation of nodes in a column of air vibrating in a tube ; we have shown how the formation of these nodes is the effect of the reflection of sound-waves either from a more dense or a less dense medium. In the same way, waves passing along a string may be reflected from the far end of it, and may, as they return, so *interfere* with new waves as to produce *places of no motion* in the string ; these *nodes*, as they are called, being separated from each other by portions in active vibration, and these portions are called *ventral segments.* Now for the experiment.

In Fig. 139, let a string be tightly stretched, as in a monochord; and while touching it with the hand in the middle let us draw the bow of a fiddle across the centre of one half, while a little rider of paper rests on the centre of the other half. By the action of the bow the string is thrown into the condition of a node and segments, the point A at which the hand was applied being the node, and each half of the string being a ventral segment. The centres of each of these halves thus become the area of greatest disturbance in that half; consequently the rider R is thrown off the string with a violent jerk.

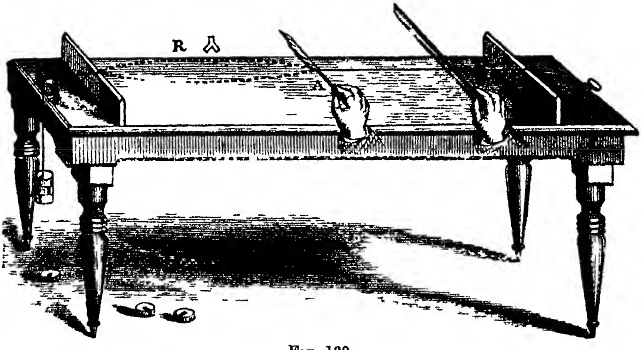


Fig. 139.

Again, in Fig. 140, let the hand be applied at one-fourth the length of the string, and let the bow be applied as before. The string now assumes the condition of three nodes dividing it into four segments, as shown in the figure. That such is the case is shown by the fact that the riders at these supposed nodes remain quiescent, while those at the centres of the vibrating segments are jerked off, as shown in the figure.

4. There is yet another manner in which energy depends on the properties of water for its *visible* results ; though for its *visible* results only, for here, as ever, not only is there for every effect a proper cause, but for every cause there is a proper effect. And this effect is "proper" not only in *kind* but in *quantity.* Sometimes this is, to all appearance,

not so; but "*to all appearance*" only, and we must dive below the appearance and fish out the facts. Let us consider the following experiments:—

EXPERIMENT 1. —*Mix 1 lb. of water at 100° C. with 1 lb. at 0° C.; we get 2 lbs. of water at 50° C.*

This is just what we should expect.

EXPERIMENT 2.—*Mix 1 lb. of mercury at 100° C. with 1 lb. of water at 0° C. The temperature of the mixture is 3° C.*

This is astonishing, for while the mercury has lost 97° C. in its

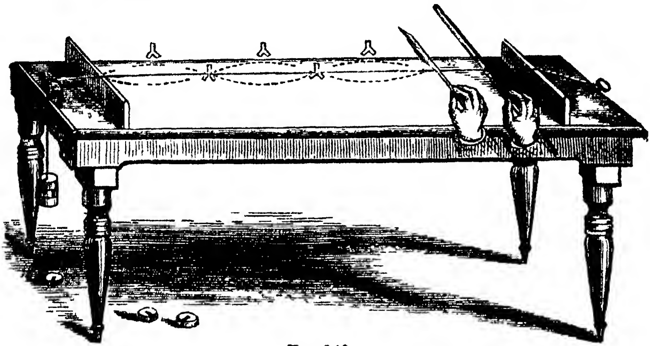


Fig. 140.

temperature, the water (which has received this heat) has gained only 3° C.

But this heat, if it could be again taken from the water and added to the mercury, would raise it to its original temperature. So that the same heat which raises a given weight of water through 3° will raise an equal weight of mercury through 97°; from which we conclude that water requires $\left(\frac{97}{3}, \text{ i.e. about}\right)$ 32 times as much heat to raise it through any given number of degrees of temperature as is required to raise an equal weight of mercury through the same number of degrees. Therefore, *the Capacity of Water for Heat* is said to be 32 times that of mercury.

The differing capacities which different bodies have for heat is usually expressed by numerical quantities called their *Specific Heat.*

The Specific Heat *of a body is the number which expresses the relation which the quantity of heat required to raise a given weight of that body 1° C. in temperature bears to the quantity required to raise an equal weight of water 1° C. in temperature;* or, more briefly—

The SPECIFIC HEAT *of a body is the number which expresses its capacity for heat relative to that of water.*

Therefore, since

$$\frac{\text{The heat required to raise 1 lb. of } \textit{mercury} \text{ through } 1^\circ\text{ C.}}{\text{The heat required to raise 1 lb. of } \textit{water} \text{ through } 1^\circ\text{ C.}} = \frac{1}{32};$$

it follows that

$$\text{The specific heat of mercury} = \frac{1}{32} = 0{\cdot}0333.$$

N.B.—It will be seen here that *the Specific Heat of Water is taken as Unity.*

The following *Table of Specific Heats* will be found useful :—

Water, ...	1·0000
Mercury, ...	0·0333
Alcohol, ...	0·062
Iron, ...	0·1138
Lead, ...	0·0314

Before proceeding further, we may here conveniently define *Temperature as a sensible effect produced in bodies by the presence of energy in the form of heat.*

To help to an understanding of the subject of specific heat, and its connection with temperature, let us take a homely illustration. The effect produced upon an old drunkard by the imbibing several glasses of good ale is small; he is used to it, he has, so to speak, a great *Capacity for Ale;* but with an abstemious man the case is different. That exact quantity of ale which scarcely affects the old tippler would make the temperate man drunk; his capacity for ale is smaller. Not that his stomach is smaller; the different capacities of these men for ale is *not* to be determined by the amount they can respectively swallow, but by the effects produced upon them by the drinking a certain definite quantity. So with the capacities of bodies for heat; *that body has the highest capacity for heat upon which an exact amount of heat produces the least effect in the way of a rise of temperature.*

It follows from this that bodies with high specific heats part with more of that energy when their temperature falls than do other bodies whose specific heats are lower. Seeing, then, that the specific heat of water is very high indeed, two results of paramount importance to man, and life generally, follow. These are as follows :—

1. In summer the waters of the earth absorb great quantities of heat, and thus prevent too great a rise in the earth's temperature at that time.
2. In winter these waters part with much of their heat. To cool a pound of water through any given number of degrees a much greater quantity of heat must be radiated into the surrounding atmosphere than is sent out from an equal weight of earth. Thus the vast waters of the ocean, seas, lakes, and rivers, act as storehouses of heat, and they also act in such a peculiar manner as to lessen the heat of summer and render less rigorous the cold of winter.

In choosing substances for Thermometers regard is had to their Specific Heats, because it is evident that a body whose capacity for heat is small is

more sensible to changes of temperature than one whose capacity for heat is greater. An examination of the table above given shows, therefore, that in this respect alcohol is a substance better suited for thermometers than is mercury; inasmuch as thermometers constructed of alcohol are the more sensible.

The Determination of the Specific Heats of Bodies is performed in various ways, of which we will describe that in which the determination is effected by comparisons of the weight of ice converted to water by the heat given out by different bodies of equal weights falling through equal ranges of temperature. The instrument by which this comparison is made is called *the Calorimeter of Laplace and Lavoisier.*

This instrument consists of three vessels of tin, as shown in Fig. 141. In the innermost one is placed a known weight of the body whose specific heat it is required to determine. This body has previously been raised to a known temperature, and is now left to cool. The other vessels, B and C, are filled with ice.

The heat given up by the body A melts a quantity of the ice in B, and the water produced by this runs out by the stop-cock D, and is caught in a vessel and weighed.

The ice in C is placed there to prevent the heat of the atmosphere from melting the ice in B. The water produced in C in consequence of the melting of its ice runs out at E, but this is not wanted for our present calculation, and is therefore not collected.

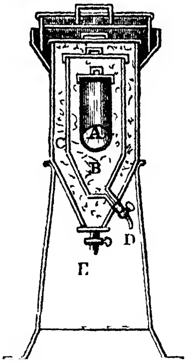


Fig 141.

From the weight of water melted by the cooling of a given quantity of matter through a given number of degrees the specific heat of that body can be calculated without further experiment; but the same result can be also obtained thus:—

Let us suppose that A is a mass of copper of a known weight, and that the weight of the water produced by the cooling of this *Copper* through a certain number of degrees is $4\frac{3}{4}$ oz. Let the copper be then removed, and let an equal weight of *Water* be placed in the instrument and allowed to cool there through the same number of degrees that the copper did. The weight of water collected at D in this latter case would be about 50 oz. Hence,

$$\textit{The Specific Heat of Copper} = \frac{4\frac{3}{4}\text{ oz.}}{50\text{ oz.}} = \frac{4\frac{3}{4}}{50} = \frac{19}{200} = 0{\cdot}095$$

This instrument is not a good one for obtaining careful results, for—

1. The experiment lasts a considerable time; there is thus the possibility that the results may be influenced by radiation and other accompanying circumstances.
2. The action of the body in A is always somewhat interfered with by that of the ice in C.
3. Some of the water produced in B clings to the ice and to the walls of the vessel containing it.
4. The mass of the body A is necessarily large, and it is not easy to ascertain its exact temperature.

We have now, in a brief and imperfect manner, shown that both *Matter* and *Energy* are apparently indestructible and uncreatable, and we have mentioned some interesting facts and circumstances illustrating these fundamental principles. The astonishing transmutations to which energy is liable without either gain or loss in its actual quantity, and the somewhat similar, though as yet less perfectly known, changes which matter undergoes, changes both physical and chemical, would lead us to jump at the conclusion that all the forms of energy, as well the unknown as the known, are inter-transmutable, and that all the forms of matter are also but different forms of one essential substance; in short, that all energies are but different forms of one energy, and all matter but different forms of the same matter. Evidences are not wanting which point us clearly along the road that leads to this great conclusion. We cannot here describe these; indeed this is not the place for them. They give us but faint glimpses of an unknown land into which we can but peer curiously and hopefully. Still at present it is an unknown land; and the knowledge that such an unknown land exists will be a fitting preparation for our next and last chapter.

CHAPTER VII.

SENSATION, AS ILLUSTRATED BY THE PHENOMENA OF SOUND AND LIGHT.

35. Sensation.

Though we neither see with our eyes, nor hear with our ears, we cannot well hear without the latter nor see without the former. Yet we occasionally do both. The objects seen in dreams are as vividly seen as those observed in waking; and the sounds also are as distinct: plain proofs these that the sensations we call *Seeing* and *Hearing* are independent of eyes and ears.

Seeing and *Hearing* are effects produced in the brain by influences usually communicated to it by the nerves, but the essential thing is *the state of the brain.* There is a certain condition of the brain which produces in us, in a wonderfully mysterious manner, the sense of sight; there is another condition which gives rise to the sense of hearing, and it matters not how these conditions are produced, let them but be produced and their corresponding sensations are invariably produced. The eye and the ear are the means appointed by nature by which exterior objects are enabled to act upon the nerves proceeding from the brain to these organs, and thus to produce in the brain the sensations proper to the influences each is able to bring to bear upon the brain. The eye is incapable of receiving from the air the vibrations which, when communicated to the brain, affect us as *Sound;* the ear cannot take up those which affect us as *Light. We may, therefore, describe the eye and the ear as organs specially adapted for receiving vibrations from media exterior to the nerves, and communicating these to the nerves for transmission to the brain, the former being peculiarly fitted for taking up and transmitting the rapid vibrations of light, and the latter being specially adapted for receiving and propagating the slower vibrations which produce sound.*

Let us now describe these organs more in detail.

36. The Ear.

(i.) Its Construction. The sensation of *Hearing* is excited in the brain by the rapid vibratory motion imparted to it by the nerves of the ear, which motion usually proceeds from some sounding body. The ear is thus frequently described as *the auditory apparatus*, a name which is apt

to mislead, because it seems to assert that the sensation of hearing is effected in it, the fact really being that hearing, like all other sensations, is the act of the brain.

Each ear may be conveniently divided into three parts, viz.—

1st. *The Outer Ear*, the function of which is to *collect* sound-waves and pour them inwards towards the interior of the head.

2d. *The Middle Ear*, the function of which is to *modify* and *transmit* these waves towards the region of the nerves, *i.e.*, towards

3d. *The Internal Ear*, the function of which is to *receive*, *arrange*, and *transmit* the waves to the nerves, and thus put them on their way to the brain.

In its passage through the ear a sound-wave thus travels through *air* in the outer ear, through *air and solid bone* in the middle ear, and through *liquids* in the internal ear, as we shall now proceed to show.

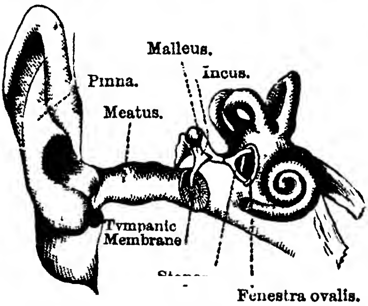


Fig 142.

(*a*) *The Outer Ear* consists of *the pinna* or *concha* (which lies outside the head and serves as a funnel to collect sound-waves), and *the meatus* or *passage*. This passage serves not only to pour the sound-waves inwards towards the brain, but also to increase the intensity of the sound by the resonance of the air contained in it. This passage is closed inwardly by a tightly stretched elastic membrane, called *the tympanic membrane*, which acts like the head of a drum. Beyond this membrane lies the cavity known as

(*b*) *The Middle Ear* (called also *the tympanum* and *the drum of the ear*). This cavity contains a chain of three little bones called respectively—

"*The Malleus*," or hammer bone;
"*The Incus*," or anvil bone; and
"*The Stapes*," or stirrup bone.

Of these, the malleus is attached to the tympanic membrane, while the stapes is attached to the membrane which covers an aperture in that wall of the tympanum which is opposite the tympanic membrane. This aperture is called the "*Fenestra Ovalis*," i.e., "*the oval window*."

The fenestra ovalis is not the only aperture in the bony wall on the inner side of the tympanum; there is another near it known as the "*Fenestra Rotunda*," i.e., "*the round window*," and it must be particularly noted that, unlike the fenestra ovalis, it has no little bone of any sort attached to the front of its membrane.

The cavity of the tympanum is, by means of *the Eustachian Tube*, put into communication with the mouth, and thus with the outer air. In this way the air on both sides of the tympanic membrane is preserved at the same density.

(*c*) *The Internal Ear* consists of winding passages filled with a watery fluid. This fluid contains most minute solid bodies floating in it, and it is by means of the vibrations imparted to this fluid and its contained solids that the auditory nerve is set vibrating and the sonorous impulses thus set on their way direct to the brain.

(ii.) ITS ACTION. Sound-waves passing through air are collected by the *pinna* and poured into the *meatus*, are here intensified by resonance and communicated to the tympanic membrane. And here we may remark that—

(1.) As sound is but imperfectly transmitted from air to solid bodies, but is easily and readily taken up by a tightly-stretched membrane, *there is great propriety in the position of the tympanic membrane, inasmuch as by it sounds are readily transmitted to the chain of ossicles lying beyond it.*

(2.) As the outer and inner walls of the tympanum are very near each other while its vertical and horizontal dimensions are comparatively large, *the tympanum serves as a sort of sounding board*, but, as its action in this way would be impeded if the air on one side of its membrane were denser than that on the other, the peculiar function of the Eustachian Tube becomes apparent.

(3.) The chain of ossicles in the tympanum are not indispensable to the transmission of sound, for the sense of hearing would not be destroyed if the tympanic membrane were removed. This membrane is doubtlessly the most active agent in the transmission of sound in this part of the ear, but the Fenestra Rotunda (which is in no way connected with the chain of ossicles) has been proved to take part in the work of this transmission. We thus learn that the air in the tympanum takes an active part in transmitting the sound-waves inwards.

(4.) The winding passages into which the fenestra rotunda opens are filled with a fluid, and the communication of the sound-waves from the air of the tympanum to the fluid of this labyrinth is much assisted by the presence of such a membrane as that which covers this fenestra, a membrane which readily accepts impulses from the one body and as readily imparts them to the other.

There are many other interesting facts connected with the human ear; for a full description of them see Kirkes's *Handbook of Physiology*, and other such manuals. That the student may now clearly understand the whole function of the auditory apparatus, we will here trace the progress of a wave from a sounding body inwards to the brain. The vibrations of such a body would first of all be communicated to the air-particles, and be by them communicated to the air in the meatus of the outer ear.

Strengthened here by resonance, the sound would be given up to the tympanic membrane, by it to the chain of bones in the tympanum, and also to the air there. Once more strengthened by resonance (*i.e.*, of the air in the tympanum), it would now be given up to the membranes which cover the oval window and the round window, and from these it would proceed to the fluids of the internal ear, and from them to the auditory nerve; by this nerve it would be communicated to the brain, and by the brain the impulse thus received would be interpreted by an act of hearing.

37. **Light as a Sensation.** It was supposed by Sir Isaac Newton—and others—that as the sensation of light was evidently produced by something which "hits" the optic nerve at the back of the eye, this something was probably matter in a very finely divided state; which matter, he conceived, was darted out at an inconceivably great velocity by all luminous bodies. *According to this theory, a ray of light would be a train of these tiny particles.* From the first there were difficulties in the way of this theory, but the authority and ingenuity of Newton long sufficed to maintain it as the most correct theory of light. We have in previous pages, however, shown that light is the production of energy communicated to the nerves, and that such energy in the nerves is the effect of the propagation to them of vibratory motion, *not* of matter.

Newton's theory is known as the *Emission Theory of Light*, sometimes called also the *Corpusculary Theory.* The more modern theory, which supposes light to be energy, and not matter, is known as the *Dynamical Theory*, or *Undulatory Theory.*

38. **The Eye.**

(i.) ITS CONSTRUCTION. The eye consists of the following parts :—

(1.) *The Sclerotic* (see Fig. 143). This may be regarded as the framework of the eye. It is white and opaque, except in front, where it presents the appearance of a pane of horn, and is called

(2.) *The Cornea.* The cornea is transparent, and has the shape and performs the function of a circular concavo-convex lens. The opaque portion of the sclerotic is lined with

(3.) *The Choroid Coat.* This is a network of delicate blood-vessels. It is lined inside with a layer of

(4.) *Black Pigment Cells.* Over the inside of this layer is spread

(5.) *The Retina.* The retina is a network of fine nerves, into which

(6.) *The Optic Nerve* ramifies.

The interior chamber of the eye is filled with a clear, transparent sort of jelly, called

(7.) *The Vitreous Humour.* In front of this is

(8.) *The Crystalline Lens,* an elastic body having the shape and per-

forming the function of a circular double-convex lens. Its outer portions (*i.e.*, those farthest from its centre) are obscured by a curtain called

(9.) *The Iris.* The colour of this curtain varies. In its centre is a circular opening called

(10.) *The Pupil,* which looks black, because we here peep through the transparent cornea, and the equally transparent crystalline lens, into the chamber of the eye, and see its black-lined walls.

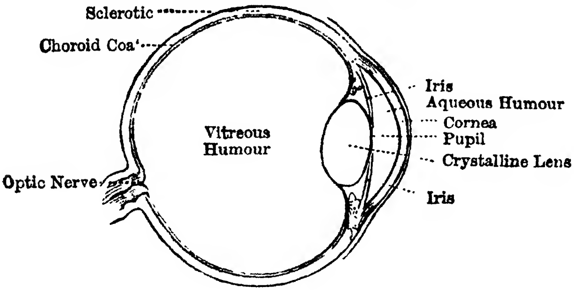


Fig. 143.

By means of apparatus, which we need not here describe, the *Iris* is made to contract or dilate according as it is necessary to admit less or more light into the chamber of the eye.

The *Cornea* is so stiff and so firmly set that it may be regarded as fixed both in position and in shape; but such is not the case with the *Crystalline Lens.* When the object to be observed by the eye is near, this lens is made to move backwards, and *vice versâ.* This power of adjustment is very necessary in the eye. In supplying this requisite for sight the crystalline lens is assisted by certain muscles, by the action of which it is rendered more or less convex, according as the object to be viewed is less or more distant.

(11.) The space between the cornea and the crystalline lens is filled with a fluid called *the Aqueous Humour.*

(ii.) ITS ACTION. It has been already stated that the cornea has the shape and performs the functions of a concavo-convex lens, and that the crystalline lens has the shape and performs the functions of a double-convex lens. The aqueous and vitreous humours also act as convex lenses, though with feeble powers compared with those of the cornea and the crystalline lens. Therefore, when the iris and the lens have been properly adjusted, the combined action of the cornea, the lens, the aqueous humour, and the vitreous humour will go to produce on the retina an inverted image of an object presented to the eye. (*Vide* p. 109.)

This image will be conveyed to the brain by the optic nerve, and consequently we ought to see inverted images of the things presented to our view. This, of course, we all know is not the actual fact; we see images in their real and not in their inverted positions. The reason probably is that the evidence of our eyes is corrected in our sensations of sight by the evidence of our sense of touch. *Light* and *Touch* thus act as handmaids to *Judgment*.

N.B.—Impressions received upon the retina of the eye do not disappear immediately on the withdrawal of the causes which excite them; the vibratory motions imparted to the nerves of the retina seem to linger there for periods which vary according to the time during which the excitation by the cause endured; they also vary in different persons; but, speaking generally, the periods average half a second. If we look at a bright object for some few seconds and then close our eyes, the image of the object still remains, as it were, quite visible. Important consequences follow from this fact; for if we see a number of objects in very rapid succession, the images of these all blend together in the eye, and we see not each object separately but the whole of them as one mass. We have already mentioned an instance of this (see p. 138), to that we may add that if a disc be divided into an equal number of sectors, of which alternate ones are painted white and black, this disc will when rotating slowly present the appearance of alternate sectors of black and white; but if it revolve quickly the eye will be unable to distinguish the black and the white, and the disc will consequently appear grey. Nevertheless, if an electric spark suddenly dash across this rapidly-revolving disc, the alternate black and white sectors will be rendered perfectly and separately apparent.

39. Irradiation. The vibratory motion imparted to the nerves of the retina does not remain confined to the area in which it is primarily excited, but spreads itself to the neighbouring nerves. Now, as we have already said, *black* is the sensation produced by a body which reflects *none* of the light incident upon it, while *white* is the effect of the reflection of *all* the light. The consequence is, that a white object on a dark ground looks larger than a black object of exactly equal size but represented on a white ground. In each of these cases the region on the retina proper to the white encroaches on that proper to the black. In Fig. 144 the two crosses are of the same dimensions, but the white one appears larger than the other. The effect thus produced is called *Irradiation*, and takes place whenever a white or other bright object is depicted upon a black or other dark ground.

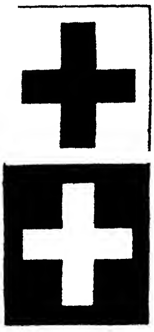


Fig. 144.

3. *Long Sight and Short Sight.* When the cornea or the crystalline lens is habitually of a too great convexity the eye is unable clearly to distinguish the more distant objects, because the foci of such objects fall before the retina and not on it. Persons whose eyes have this defect are said to be short-sighted, and for them eye-glasses (spectacles) with diverging lenses are required, because by these the focus of the rays is thrown farther back, and so reaches the retina instead of falling some distance before it.

Sometimes, however, the lenses of the eye are habitually not sufficiently convex, and consequently the persons so afflicted are unable to see the nearer objects placed before them. This is called *Long Sight,* and is remedied by the use of convex glasses; by means of these lenses the rays are focussed *upon* (instead of *behind*) the retina, and distinct images of these objects are consequently formed on it.

40. Conclusion. In these few and imperfect pages we have striven to the best of our ability to make things understandable, and thus to give scope and action to the reasoning powers of our readers. We might here, after the manner of the French Revolutionists, conclude our work by exalting *Reason* as chief goddess, with the *Sensations* at her feet; but we prefer rather to preach *Humility* and *Diffidence in Judgment,* inasmuch as we see how falsely even our vaunted sense of sight may serve us, and how liable to error must our judgments ever be, since the handmaids which wait upon the mind and occupy themselves in feeding it are so very untrustworthy.

THE END.

PRINTED BY G. PHILIP AND SON, LIVERPOOL.

L

6